JUNE 1950

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

Turbo-Topics

TURBO-MIXER CORPORATION UNIT

GENERAL AMERICAN TRANSPORTATION CORPORATION

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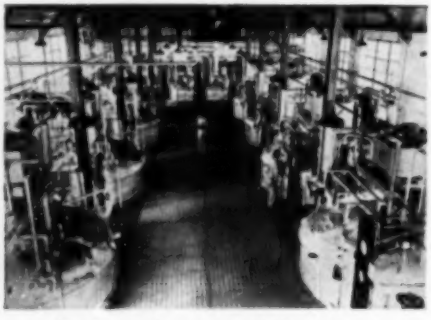
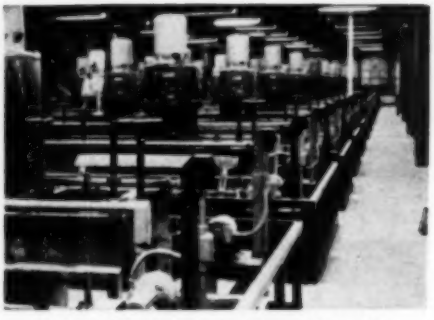


Streptomycin fermenters with Turbo-Mixers at Merck & Co., Inc., Elkton, Va.



68 Turbo flotation cells for roughing and scavenging at the Noralyn plant of International Minerals and Chemical Corp.

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The A.I.Ch.E. just passed an important milestone in its history last month (after we had gone to press) when it obtained member number 10,000. Ten thousand of the world's best chemical engineers in one organization, such as ours, is certainly something to be proud of and something to talk about.

The A.I.Ch.E. is now 42 years old and the next goal is 15,000 members. We ought to have them, and more, by the time our Golden Anniversary rolls around in 1958. But in dynamic organizations such as the A.I.Ch.E. we don't stop with 10,000, for even now we are well over 10,100—all chemical engineers—all the best there is.

As billed here in May, this month C.E.P. publishes the papers in the Training Engineers in Industry Symposium held in Pittsburgh. Here many worth-while ideas are offered by the speakers and a responsive audience. Progressive industrial education at its best!

This month's Marginal Notes contains a valuable review for scientists and engineers concerned with nuclear physics and nuclear chemistry. The book—"Trilinear Chart of Nuclear Species," by William H. Sullivan.

Again the Data Service in this issue contains the latest literature on equipment and chemicals. Encircle the numbers as directed and send in the card. Your needs will be our immediate concern.

Good jobs await good chemical engineers. When looking for a new assignment use our Classified Section. See Situations Open in this month's issue. A supervising chemical engineer and a market analyst are wanted.

Something new in ion exchange developed by Rohm & Hass is the subject of a news story in this issue. Read about the Monobed technique on page 18.

This issue contains a preliminary report on the meeting in Swampscott. Look for details and pictures in the July issue.

Something else in next month's issue which you will want to read thoughtfully—the beginning of a two-part Industrial Waste Symposium.

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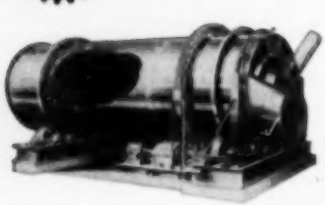

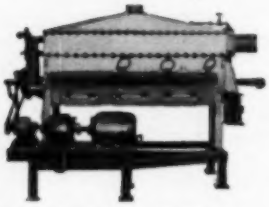

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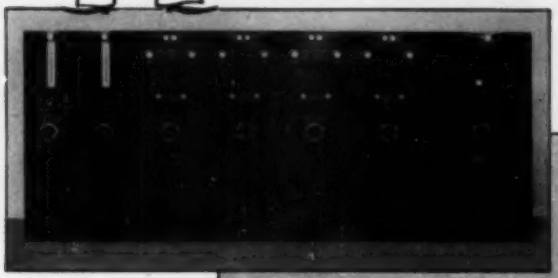

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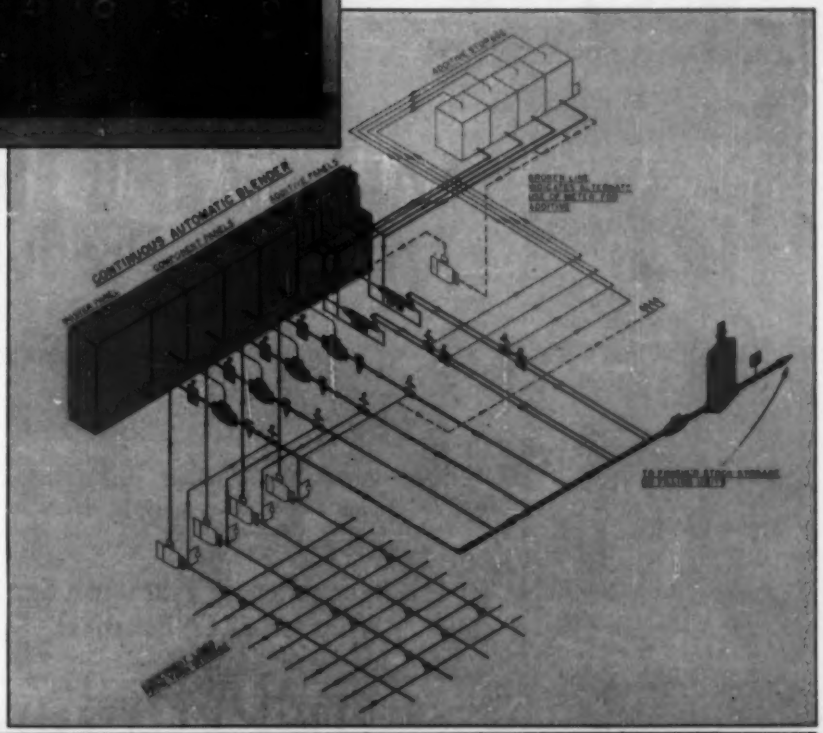

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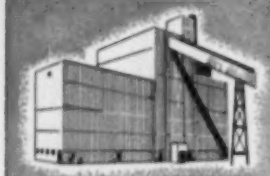

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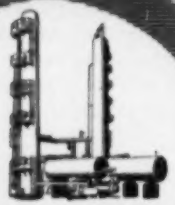

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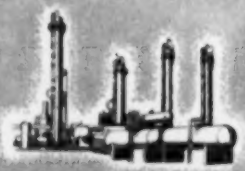

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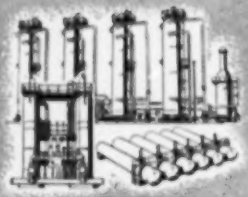

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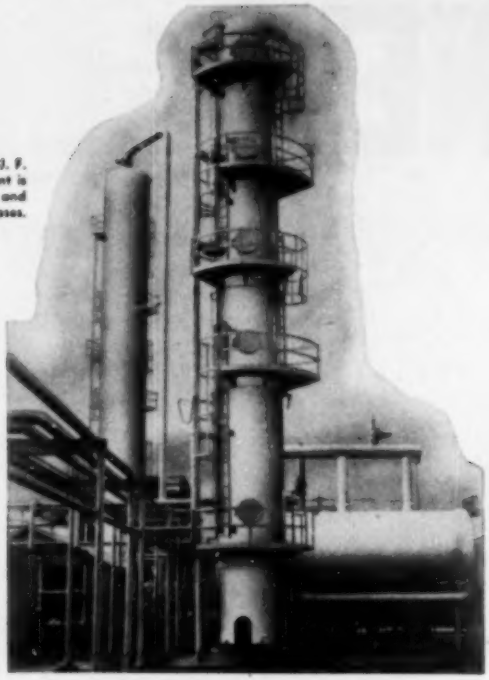

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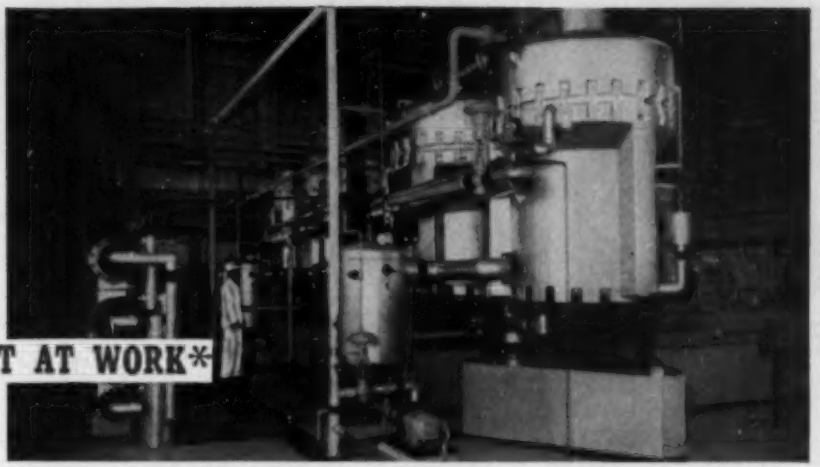

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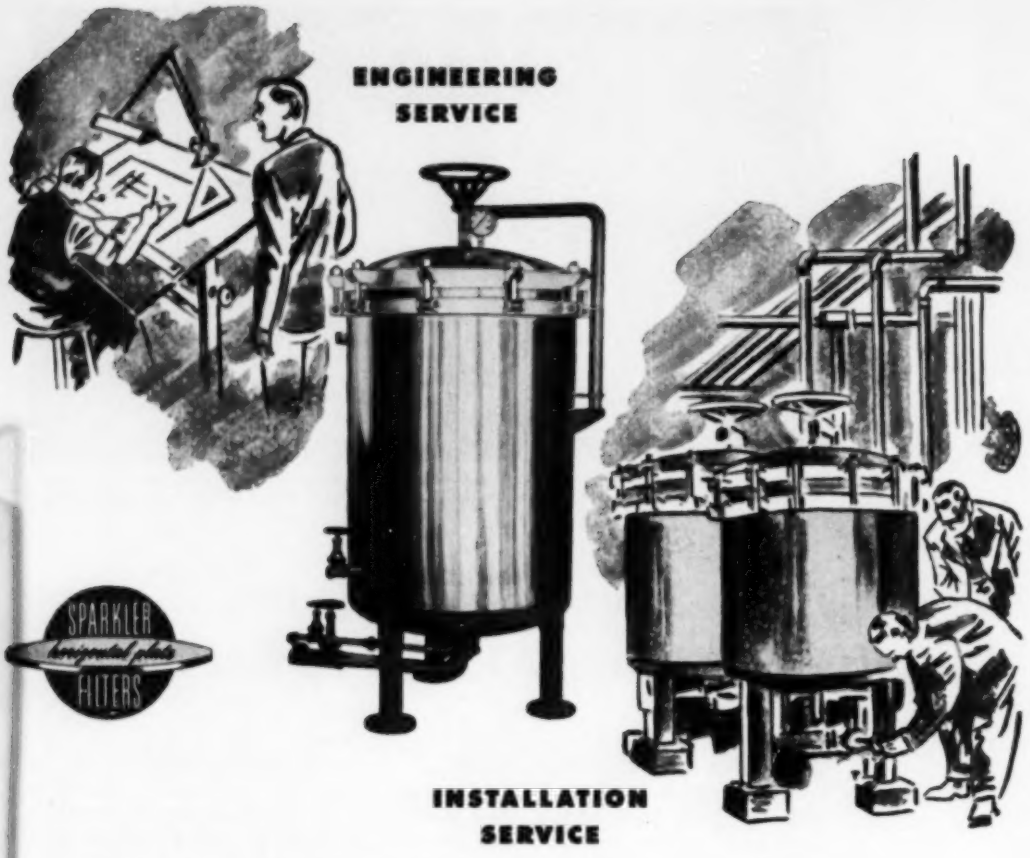

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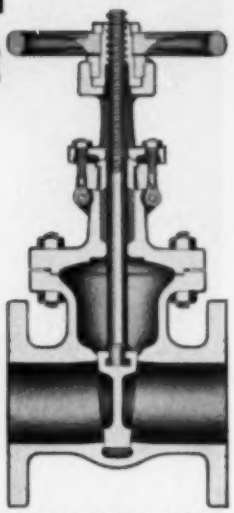

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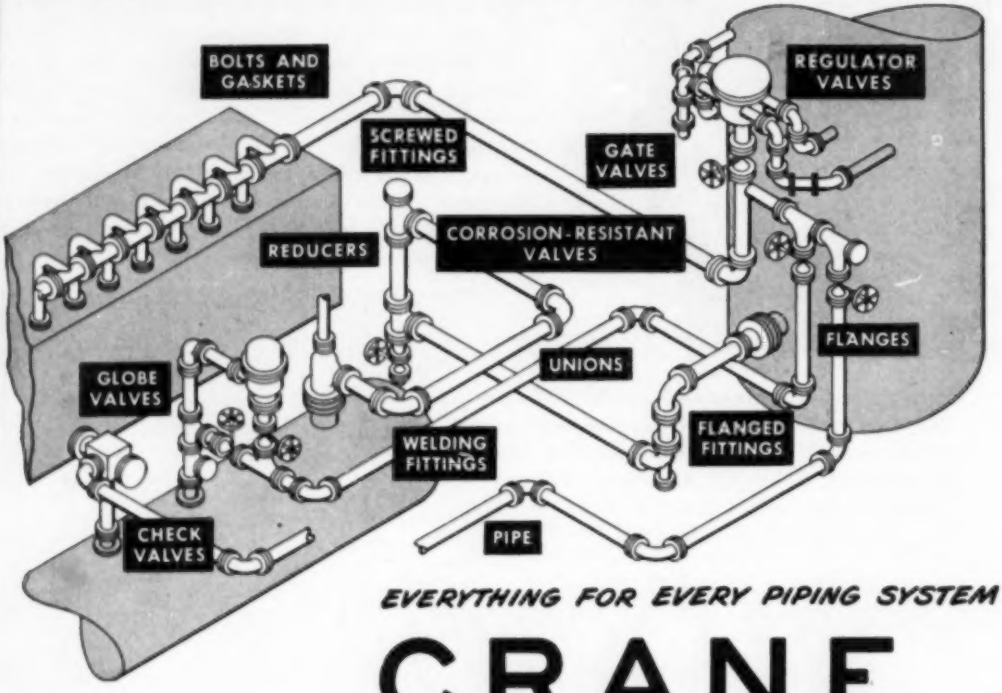

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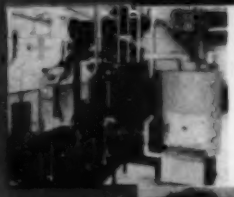

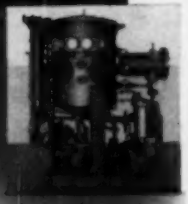

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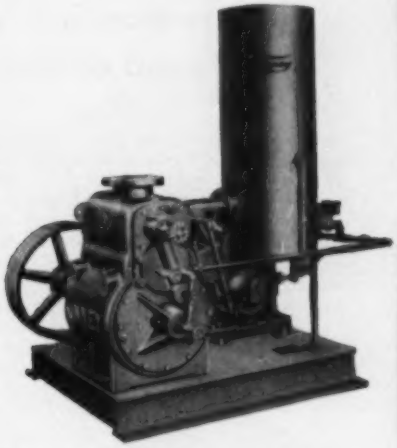

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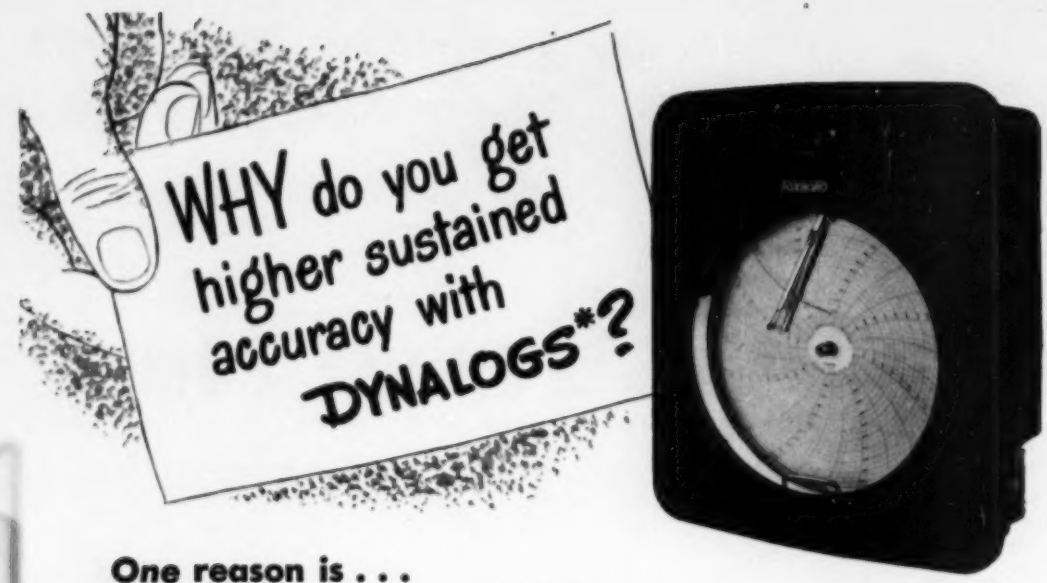

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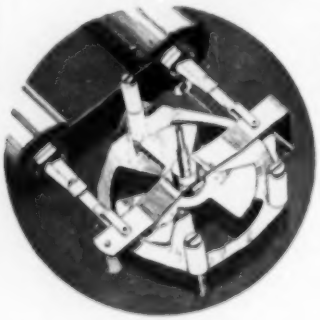

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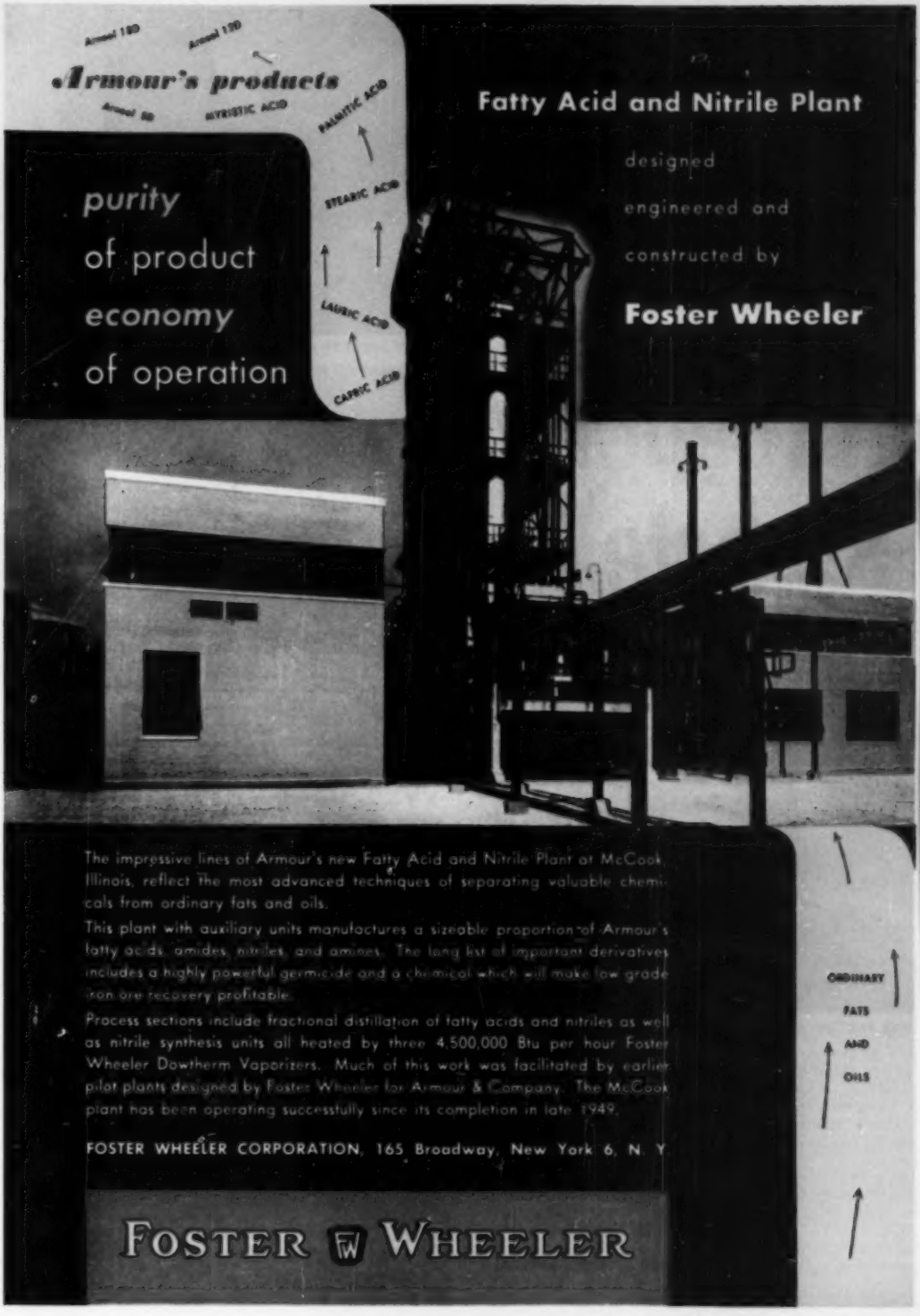

The impressive lines of Armour's new Fatty Acid and Nitrile Plant at McCook, Illinois, reflect the most advanced techniques of separating valuable chemicals from ordinary fats and oils.

This plant with auxiliary units manufactures a sizeable proportion of Armour's fatty acids, amides, nitriles, and amines. The long list of important derivatives includes a highly powerful germicide and a chemical which will make low grade iron ore recovery profitable.

Process sections include fractional distillation of fatty acids and nitriles as well as nitrile synthesis units all heated by three 4,500,000 Btu per hour Foster Wheeler Dowtherm Vaporizers. Much of this work was facilitated by earlier pilot plants designed by Foster Wheeler for Armour & Company. The McCook plant has been operating successfully since its completion in late 1949.

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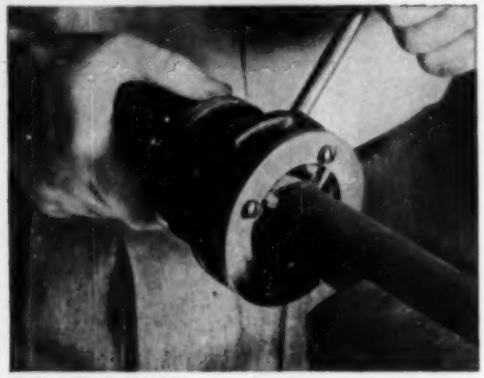

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OPINION AND COMMENT

ATOMIC ENERGY RESEARCH AND DEVELOPMENT

SEMIANNUAL reports of the Atomic Energy Commission contain information which is of considerable interest to chemical engineers. In addition to usual information on production and program, general advances in, and plans for, research and development are outlined. Data on all fields of nuclear physics, chemistry and engineering are presented. The most recent report, the Seventh Semiannual Report, presents a review of research programs, and, so far as they can be publicly stated, the results attained in the physical sciences and engineering development.

Our great structure of nuclear technology has been built on an extraordinarily slim foundation of basic knowledge about the atomic nucleus. Pure and applied research in the physical sciences is indispensable to the fulfillment of national atomic energy development and to the maintenance of the United States' position in this field. The field of basic research is almost unlimited in scope, and in applied research or development alone, numerous problems must be investigated.

What then is the magnitude of the effort in this country? What is the manpower involved? What is the place of chemical engineering in the picture?

For both applied and basic research the Atomic Energy Commission maintains eight major installations completely owned by the government, and four major university-owned installations. These constitute only a part of the effort in these fields. Another one third of the research effort cost-wise, one half in manpower, is carried on by scholars on the staffs and in the laboratories of many universities, research institutions, industrial organizations, and other government agencies. The Commission wholly supports 90 such projects at 55 institutions. A similar program for basic research is maintained by the Office of Naval Research and the Commission has joined with this office in supporting some 63 projects at 39 institutions.

The magnitude of this atomic energy undertaking is reflected in the estimated costs for 1950. About 8 million dollars is estimated for the operating expenses associated with off-site contracts for physical science research. This is to be compared with about 23 million dollars for the 12 major atomic energy installations. In addition to this 31 million dollars, 25 million dollars is being spent during this fiscal year on new construction and equipment. These figures do not include those associated with the reactor development program, involving 33 million dollars in operating expenses, 12 million of which is in off-site projects. Not included also are the expenditures for research in the biological and medical sciences amounting to 17 million dollars in 1950, 7 million dollars of which is for off-site projects. These costs for operative expenses and new construction for research and development amount to 106 million dollars. Costs for the production of fissionable materials and military utilization run to larger figures and constitute the major portion of the annual appropriation for atomic energy.

Of more interest are the manpower figures listed in the Seventh Semiannual Report. Approximately 10,000 scientific and technical people work for the Commission. Of these 2,500 are on off-site projects, about equally divided among physical sciences, reactor development, and biological and medical sciences; 500 are on the Commission's staff in Washington and in the several field offices; and 2,900 are fully employed on research and development at Commission-owned sites. Another 4,000 work on the development of new weapons and on research and development directly associated with the production of fissionable material.

The contribution of chemistry and chemical engineering to the atomic energy program is a considerable one. From personal observation, one would estimate that fully one third of the scientific people are chemists or chemical engineers. Space does not permit a description of the extremely interesting and varied types of problems these men are tackling. Suffice it to say, that the frontiers of both basic and applied science are being expanded rapidly. In many cases process and engineering design is applying data on the ragged edge of scientific knowledge. New techniques are being developed in all fields. Many of them have already been released and have been of value to the chemical industry.

Engineering design and construction of new plants are generally subcontracted to industrial firms. By this means and through the off-site projects, as well as private research not covered by the Commission, scientific people are being attracted to full-time employment in one of the fields of atomic energy development. In addition, special programs for training have been established at the various sites.

Technically the national atomic enterprise makes progress only as men of talent and training are attracted and the special equipment is placed at their command. For a continued growth a steady flow of engineers and scientists into fields associated with atomic energy must be maintained.

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TRAINING ENGINEERS IN INDUSTRY

An industrial problem of some magnitude to management is aired here . . . concrete examples of the how, why, when, and where of other companies enthusiastic in their conception of training of engineers, are listed . . . for those who do not have a training program, here is a good beginning, for those who are already using the method, it is a valuable comparison . . .

INDUSTRIAL TRAINING PROGRAM— A PRACTICAL INVESTMENT

K. B. McEACHRON, JR.

Manager, Technical Educational Division, General Electric Company, Schenectady, New York

ALMOST every industrial concern has studied the problem of training its personnel, and has developed a program to meet its particular problem. The extent of industrial training, generally, is suggested by the many companies having full- or part-time training directors. Most attention has been given, in the past, however, to training programs for noncollege graduates. Such courses as those for the various trades and the upgrading of employees are common.

There apparently has been a strong feeling that the more advanced a person's education the less need there is for an industrial training program to develop his full potentialities. In fact, many companies, in recruiting college graduates, have insisted that their training in college be such as to make them immediately valuable in a particular narrow field. Through alumni and other contacts such concerns often attempt to dictate what courses the colleges should give. The fragmentation of normal engineering curricula under such pressures is indicated by the hundreds of different curricula now offered by American colleges. Even more serious is the overcrowding of engineering curricula whenever courses are designed to impart specialized knowledge rather than to develop an ability to think.

Collegiate education, however, can be expected to provide a fundamental background only, and teach young people to learn from experience. Graduation from college is truly a commencement—the beginning of the period of learning from experience. The company which fully appreciates the potential of its technical personnel will be quick to recognize the value of a training program to develop this potential. College experience has, in most cases, been a relatively artificial period involving little contact with practical engineering or business problems.

Many training programs for technical personnel which now exist in industry began largely as a matter of expediency. In General Electric, for example, there were no engineers available in the early days to design, test, install, or even operate, the equipment which the company manufactured. College programs were devoted largely to civil and mechanical engineering. The company had to develop an effective on-the-job training program to supplement the education of new employees. Most of this early training was obtained by actually testing and experimenting with the finished products. Some companies even established their own undergraduate educational programs during this time. For a brief period in the late 1920's we also experimented with undergraduate education. However, the advantages in selecting college graduates from hundreds of different educational institutions soon led us to abandon any plan to compete with the colleges in undergraduate programs.

KARL B. McEACHRON, JR., following graduation from Purdue with the degree of B.S. in electrical engineering joined General Electric Co. in 1937 at Pittsfield on Transformer Test. Was selected for the "A" Class of the advanced engineering program and subsequently supervised the "A" Class. In 1942 he was placed in charge of advanced engineering program, and in May, 1946, took over the educational activities for the chemical department. Two years later he was named manager of technical education division of the executive department at Schenectady. He is a member of many engineering societies and author and co-author of several technical articles.

Essential to the development of an adequate training program, particularly for engineering personnel, is the active and personal support of management. Education and training in industry cannot exist apart from the ultimate requirements of production. However, if the training program is left entirely to operating units it is often compromised for short-term gains without proper consideration of long-range objectives. If the maximum benefit is to be derived from training activities, they must be "built-in" to the thinking of engineering supervision at every level and not simply given token approval. To create this desirable condition, supervision must participate in the planning of the training program and must be kept continuously and actively informed of its progress and its problems.

Many training activities have suffered from overenthusiasm on the part of those directly responsible for them. Particularly where there is skepticism concerning the value of such activities, the initial step should be extremely modest and the men assigned to the training program unusually well selected. If the need for men somewhat exceeds the number in training the whole plan will be more likely to succeed than if the supply is always equal to the demand or perhaps a little above it. The attitude of men participating in a training program is also much better when sufficient permanent openings exist for those satisfactorily completing training.

Important Emphases. During the training period the engineering graduate should gain that training and experience which it has not been possible for him to obtain in college, and to do so in such a way that at its completion he assumes the full responsibilities of a professional engineer. The type of experience provided at this point will probably do more to shape the attitudes of the engineer than any other experience he will ever have. Where the primary emphasis in college has been on the study of engineering fundamentals, the emphasis in industry must be on the application of these fundamentals to actual engineering problems. The heart of an effective training program must, therefore, be broad industrial experience. Such experience is best gained through a series of short assignments in different sections and types of work. Where the company's business includes several lines or products, diversity of experience is desirable.

Each training assignment should provide ample opportunity for actual work experience. Not only will this emphasis on "learning by doing" help to sell the training program itself to operating units, but it is also a sound educational policy. To stress the point that men in training are to be regarded as contributing members of the sections to which they are assigned, we have found it desirable to charge the sections the full salary of men on assignment. This practice also helps to encourage the assignees to put maximum effort into the job at hand. So integral a part of the operating units of the company have our training programs become that we are continuously being approached by such units for men even on these temporary assignments as well as for men on a permanent basis at the end of the training period.

Industrial Experience—and More

Although job experience is essential to effective training, such experience alone will seldom be sufficient to develop the engineering graduate to his full potential. In the few years which a man spends in college he cannot hope to obtain all the technical knowledge he must have to discharge his engineering responsibilities successfully. Furthermore, if the engineering college has properly concentrated upon the fundamental principles of engineering, he will need a considerable amount of technical training in specialized fields of particular interest to his company. Most industries will also recognize that the course method of instruction, which is used in most engineering colleges, tends to produce *problem* solvers rather than *project* solvers. In other words, the separation of technical education into discrete courses tends to prepare college graduates to solve specialized problems in those individual areas but not comprehensive problems involving many areas. There is need for a type of classroom instruction which will integrate the course material given in college and direct the application of engineering fundamentals to current technical problems. Where necessary, such instruction should make provision for extending the technical knowledge of engineering graduates beyond that received in college. But the principal objective should be one of refinement and of integration.

The method of organizing and supervising training activities differs considerably from one company to another even though the training programs are quite similar. Considerable thought should be given to this phase, however, as it may provide an opportunity for further training of a somewhat different character. Although the principal purpose of training engineering graduates should be to improve them as engineers, we have found in the General Electric Co. that by using young men to supervise portions of the training program, we have developed leadership as a by-product of training. Young men who have been with us only a few years are given almost complete responsibility for the organization of educational activities. Although such young men do not have the background that certain phases of the work require, they are encouraged to call upon others in the company for assistance and guidance. No one, however, will make decisions for them. The enthusiasm which they bring to such work is high, since they have only a year or two in which to contribute their best ideas to the administration of the training classes. Supervision thus becomes a creative opportunity for each man to revise and improve the training which he received the year before.

For Example. When our chemical department was formed to extend the company's interest the recruiting and training of adequate personnel were given early attention. The training programs of other companies were reviewed and compared with our own. As a result, a chemical training program was organized along the same general principles, previously described: varied work assignments with a strong emphasis on "learning by doing," an intensive classroom program to make more useful to industry the usual technical education, and an opportunity to develop leadership in young men through supervision of training activities.

Although some form of training program was necessary to the future of the chemical department, other units were regularly employing chemical personnel: such as the development laboratories interested in insulation, protective coatings, and other problems of materials. A training program serving the company as a whole was therefore considered to be practical, and potentially more effective than one for a single department. An informal committee, representing the units concerned, was selected to aid in establishing a definite training plan. From the beginning, therefore, operating personnel were directly involved in the plan's organization and the selection of the first supervisor. Policy questions such as the length of the training program, individual training assignments, etc., were determined by the committee with a minimum of objection from operating groups. Committee members have always helped support the training plan in their own units.

The present program consists of from three to five three-month assignments for each man in training. Although some consideration is given to individual preferences, the primary objective is breadth of work experience. At the conclusion of each assignment, each man is carefully rated on his performance and his capacity for future growth. These ratings are periodically discussed with each trainee as an aid to his improvement. After his second or third assignment, placement possibilities are discussed with him by the program supervisor. Interviews are then arranged with those interested units which seem most suitable for the particular trainee. The variety of available placements is so great that seldom is it impossible to match man and job. Each fall, about 20 men are selected on the basis of interest and ability for an intensive course in process technology. The course is approximately nine months in length and consists of one four-hour class each week. A single, comprehensive, technical problem, assigned each week, is the principal factor in developing the ability of these men to apply their technical knowledge effectively. The class hours include lectures, quizzes, and problem discussions to supplement the working of the weekly problem. From the first-year class in thermodynamics and basic physical chemistry about half the men are selected for a second year in more specialized and advanced theory. This class has concentrated usually on some advanced phases of chemical engineering. Men completing this two-year technical program have a unique combination of theoretical education and practical training.

Although the first supervisor of the program was, necessarily, drawn from outside the training activities, subsequent supervisors of the first- and second-year courses and of the whole program of training and education have been drawn exclusively from the training group. In this experience, we have

realized again how great are the enthusiasm and eagerness of men so selected to do an outstanding job and how effective such an attitude is in the training process itself. By carefully selecting from the best qualified the one or two supervisors required each year, we can have in such positions for a year or so men whose potential in the organization is far greater than is that of the average training director. The quality of our training programs is due in large measure, we believe, to this practice.

Dividends from Industrial Training. Advantages of an adequate training program for engineering personnel can be fully appreciated only after actual experience with such a program. They will also vary, depending upon the type of industry and the particular company involved. Where the program has the active and continuous support of management and largely achieves its objective of the orientation and integration of young men into industry, certain definite results can reasonably be expected, however.

Training assignments in various operating units broaden the experience of young men and give them a more accurate picture of the company's operations. In large companies, new technical employees will be only vaguely familiar with the products or services which the company sells. During training an opportunity exists to learn more about these, including the standards which must be met before marketing. While in training, engineering graduates also become more familiar with the permanent positions available and will make a more intelligent selection of the one which best suits their interests and abilities. Even after transfer to a permanent position, the breadth of the training experience will prove valuable in working with other units of the organization. The personal contacts developed among associates during the training period is of no small assistance. One supervisor has somewhat humorously remarked, "Not only do they know who to call on for help in solving a particular problem, but they also know how much to believe of what they are told!"

Divisions of the company, through direct contact with men in training, have an opportunity to evaluate their performance in advance of selection for permanent positions. Men on an assignment of three or four months in a division have a much better chance of demonstrating their true abilities than in an interview or series of interviews of a few hours or days. It is important to note here that men recruited for a training program should be as carefully selected as for direct employment in a permanent position. The training program should not be used as a marathon in which all but the top 10 or 20 per cent are weeded out and released. Every man should be employed with the expectation that he will be a permanent member of the engineering staff. If a healthy attitude toward the training program is to be developed and maintained the only releases that should occur are those where errors were made in the original recruiting process.

Classroom instruction, associated with training activity, develops technical versatility and makes engineering education more effective. The men who have completed our advanced technical programs, for example, form the nucleus for solution of our most difficult technical problems. Thus during the war we had a group of well-trained men who had not been educated narrowly in a single specialty, but who were in the habit of tackling new projects. These men were transferred directly from refrigeration, air conditioning, and other peacetime jobs to greatly expanded divisions such as radio, superchargers, and armament control. Likewise, in normal business operations, the most valuable technical employees are those whose academic tools are so sharp that they can be shifted from one tough, technical problem to another with little regard to their individual background.

Placing supervision or training activities, particularly orientation programs, in the hands of relatively young men provides a more sympathetic and understanding approach to the problems and attitudes of the new men in training. Such supervisors work out the problems of the job with their men, guiding and leading, rather than directing or ordering. All are learning more about the job together. An unusual spirit of teamwork is thus developed between supervisor and men—a spirit which extends even beyond working hours and into social and athletic activities. Many young men who have had this type of supervising responsibility for a year or two after completing their own training experience can later be given positions of leadership in the operating units. These men will bring to such positions an unusual combination of technical and administrative experience.

There is more and more interest in industrial training programs among today's engineering graduates. Many of them recognize their lack of industrial experience and their consequent inability to make an intelligent decision about any particular, specialized job. They welcome the opportunity to become better informed through an industrial training program before selecting a permanent job in sales, engineering, manufacturing, or any of the other functions of business. This attitude, on the part of the technical graduates, is, of itself, a powerful argument for considering seriously the development of an adequate training program.

Building for the Future. An industrial training program for technical graduates is truly an investment—and like a financial investment, will "pay off" only over the years ahead. A company which is concerned only with immediate gains and which attempts to organize training activities on such a basis is generally heading for trouble. Technical personnel and their adequate integration into American industry is a more exacting task and a potentially more profitable one than controlling inventory or purchasing machinery and material. In establishing a new line or going into a new business, as much or more attention should be given to developing adequate technical personnel through proper training activities than to any other factor. The success of the enterprise may well be determined by the extent to which, formally or informally, training is encouraged and its function in such success recognized.

TRAINING PROGRAM FOR CHEMICAL ENGINEERS IN PETROLEUM INDUSTRY

A. J. JOHNSON

Vice-President in Charge of Engineering,
Shell Development Company, San Francisco, California

THIS discussion is intended to outline a training program for chemical engineers in the petroleum industry. This program also applies, to a large extent, to training men for the associated petrochemical industry. It seems to me more important to dwell on the objectives of the program and the require-

ments for a well-trained chemical engineer than to give a detailed description of how this training program is conducted. The program itself will vary somewhat with the individual and with the availability of experienced men and specialists to assist the trainee in rounding out his knowledge to meet what, we feel, are the basic requirements to become a good chemical engineer.

Type of Chemical Engineering Involved

To make clear what our program attempts to accomplish, certain characteristics of chemical engineering in the petroleum industry will be detailed. Although at some time during his career a man will be faced with all phases of chemical engineering and will be called upon to handle problems much outside his chosen profession, the following points seem to characterize the industry and the chemical engineering involved in it. First: petroleum processing is characterized by large-scale continuous equipment; second: some 60-70 per cent of the invested capital in refineries is in separation processes, predominantly distillation and extraction, with a large part of the remainder in reaction processes; third: it is a progressive industry with a high rate of obsolescence of equipment and processes, since new processes are being continually installed; and fourth: the ever-expanding, and highly competitive market situation requires continued effort to obtain maximum throughput from every unit.

Processing units are large and continuous, the industry is highly competitive, and the investment is high. In such an industry, chemical engineering must be accurate, must look for marginal savings, and the units must be designed for a minimum of downtime. A maximum of precise instrumentation is usually justified to improve yields and quality by better control, and hence a thorough knowledge of each process is required of both the designer and the operator.

Minimum Knowledge Required of Chemical Engineers

The minimum knowledge required of a chemical engineer may be divided into two classes: the fundamentals (beyond the first two years of college courses common to all technical graduates), and the techniques. Regarding the former, a new engineer should have a fair knowledge of the nature of atoms and molecules and the electronic theory of chemical bonds; he should understand the nature of gas and liquid states and the physical chemistry of phase boundary; he should have a thorough grounding in stoichiometry; he should know well the thermodynamics of energy balances, phase equilibria, and chemical equilibria; he need know only the elements of analytical and organic chemistry; it is desirable that he have facility with differential equations; and finally, he should know the theory of momentum, mass, and heat transfer. The graduate does not as a rule know all these as well as he should, and one part of our training program is to fill in the gaps so as to give him a well-rounded background in fundamentals.

It is not necessary to discuss the value of all these minimum requirements, but a few points should be emphasized. We all know that the solution to problems of unit design and operation can be no better than the basic data used. The physical chemistry laboratory in a research organization, or the published results of other investigations, are the source of such data. It is imperative, however, that the chemical engineer's background knowledge be sufficient to permit him to understand, interpret, correlate and assess properly the value of such data. Centralized basic data groups in a company do not eliminate the need, in a chemical engineer, for a thorough understanding of these basic data. Then, too, facility with differential equations has been mentioned. Mathematics is the language of science and it is important for the engineer to be able to write and understand this language. (Probably in no other phase of his academic training am I more critical of his college teaching.) In most cases mathematics is given too much as a formalized course in which a student is taught to solve problems established by someone else. The engineer usually has a good mathematical vocabulary, but does not know how to speak the language and to think in it. I do not wish to leave the impression that good chemical engineering requires each man to be an outstanding mathematician, but it is none the less an important fact that in the chemical engineering required for the petroleum industry, most worth-while accomplishments have been closely associated with good mathematical interpretation.

A. J. JOHNSON joined Shell Oil Co. as an analytical chemist at the Norco (La.) refinery, after receiving his Master's degree from Tulane University. Rising through a succession of refinery technical positions to that of assistant manager of the gas plants, in 1936 he became a senior technologist in the development division (manufacturing department) in St. Louis, becoming assistant manager in 1939. Transferred again to be assistant superintendent of the Houston refinery, he was then made chief engineer of the Shell Development Co. in San Francisco to build up the chemical engineering activities of that company. In 1944 Mr. Johnson was appointed vice-president in charge of engineering.

You may wonder why only the elements of organic chemistry are necessary in an industry dealing primarily with organic compounds. It is simply because we believe it is the function of the research organic chemist to provide the advanced thinking in this field, while the chemical engineer need only be able to understand his findings.

For the minimum knowledge of techniques, the engineer should know methods of design of countercurrent separation processes, methods of calculating the dynamics of two phases (whether gas-liquid or gas-solid, in pipes or in vessels), methods of handling problems involving mass transfer across a phase boundary, and methods of handling problems involving catalytic and homogeneous reactions. He should have an elementary familiarity with process apparatus—valves, columns, separators, exchangers, furnaces, filters, pumps, compressors and internal combustion engines. Finally he should have a clear understanding of the economics of capital risk.

As in the case of fundamentals, it should be evident why we consider these techniques as minimum requirements. In most cases we find the new addition to our staff has a fair knowledge of techniques; in fact he has usually learned more technique at the expense of some needed fundamentals, or knowledge in related fields of chemical engineering, than we immediately require. Probably this is due to the fact that it is harder for us to teach the fundamentals than the specific techniques required in our industry. We prefer that the man will, if anything, have overemphasized the fundamentals in his academic training.

In most cases, the graduate will have little knowledge of the economics of capital risk, and it is necessary to indoctrinate him, not only with general knowledge on this subject, but also with that peculiar to our industry. This includes management's views regarding capital amortization, overhead burdens, and the various factors contributing to operating cost. An acquaintance with methods of cost accounting is helpful. These two, economics and cost accounting, will give a fair conception of the direction in which profits are likely to be improved. After some experience he will understand the compromise between

idealized chemical engineering and business conditions, so that the right combination will provide the maximum profit under various business conditions of cost versus market value, and cost versus quality of products. Unlike the synthesis of individual chemicals, where the ultimate in quality is production of a chemically pure compound, the quality of petroleum products is always undergoing changes and improvements to meet new specifications and requirements, and the ultimate goal in quality is never completely clear nor attainable at reasonable cost.

Nature of Work Required of Chemical Engineers

The work of the chemical engineers in the petroleum industry (or for that matter in most industries), will fall into five general categories: the improvement of yield, quality and throughput in existing plants; reduction in operating costs of existing plants; adaptation of existing equipment to new services; development and design of new processes, and the exercise of technical control over the operation of plants. In performing this work they will exercise varying degrees of administrative, executive and specialized knowledge depending upon the position which they hold, but in all cases the chemical engineering requirements will probably fall under these five types. Only when chemical engineering or other technical knowledge has become background information used in another field will the type of work be much different. It is perhaps useful to point out in which parts of the industry there will be more of one type and less of another. In the Shell company, technical service groups known as Technological Departments are located in the refineries. Their primary work deals with daily operation, changes in operation, and modifications to existing units. The development and design of new processes rest in the hands of those chemical engineers more closely associated with the research and development groups of our company. Men who have what is often called a "flair for operation" and who are more interested in the day-to-day application of their professional knowledge in techniques will gravitate towards such functions as those of the refinery technological staffs. On the other hand, those men who are best grounded in fundamentals, and who are more suited to the project type of work, are likely to be associated with development groups for the design of new processes. Specialists are likely to be associated with research and development groups. A specialist often will be used on a consulting basis for special problems in the operating field, but for him to remain there very long would result in his lagging behind the progress made in his field, and his knowledge would become out of date. The specialist therefore must spend most of his time developing new ideas and techniques, and less on the application of his findings.

Chemical engineering has a broadening scope in our industry. The practice of our profession has long since departed from the mere application of the knowledge of unit operations. Because of the foundation knowledge in other sciences, and by the very nature of their work, the chemical engineering groups have provided the coordination, the task force, which brings together for assessment and application, the data arising from all technical sources. No longer can the chemical engineer be satisfied with the development of a simplified flow sheet, with a heat and material balance, giving some indication of the selection of predesigned apparatus. His function begins with the research itself, where he assists the thinking of the pure research man by process evaluation and reevaluation. He must know more about equipment design than ever before, since the installation of increasingly complicated processes does not permit mechanical designers alone to make the choice; he must be able to utilize the complicated measurement and control apparatus developed by instrument experts and integrate them into the process properly since the apparatus designer is in no position to do so. He must know more about materials application, both the physical properties such as arise from metallurgy studies and the chemical properties such as arise from corrosion studies. In short, he must integrate all data arising from research chemistry, physical engineering, and economics and direct them towards the best finished process. Chemical engineering has definitely become the coordinating force behind all phases of the development of new processes, broadening its field particularly in the direction of physical engineering.

Objective of Training

The sole reason for training a man beyond the academic learning with which he arrives from the university is to make him a more valuable employee. A good training course increases a man's value in three ways. It broadens his technical knowledge, it helps him to know himself, to find out what he can do best, and it gives his superior an early estimate of his potentialities, enabling his progress to be directed by something more than trial and error. During the course of training, a man should have the opportunity of increasing his knowledge of both techniques and fundamentals by performing assignments which are selected primarily on the basis of their instructional value. While he is learning these fundamentals and techniques, he should be given a sufficient variety of tasks by which he can take his own measure of his ability in order to find those fields of endeavor from which he will gain the most personal satisfaction. While this program is under way his supervisor will obtain an estimate of his aptitude and the type of activity in which it appears he will most likely be successful. Thus we can arrive at an early understanding with the man of his desire and ability in various directions.

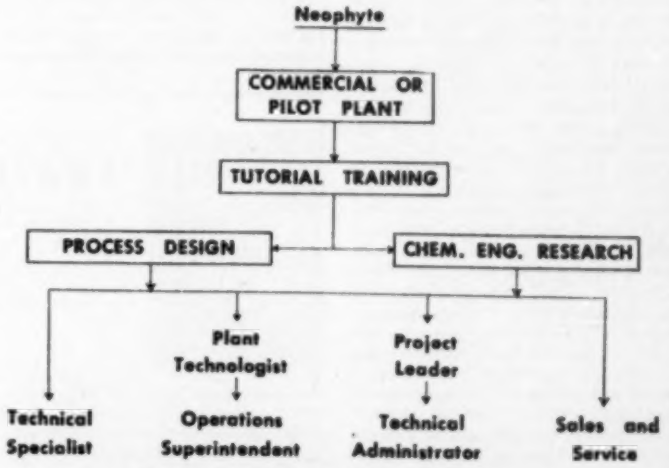

Fig. 1. Steps in Chemical Engineer's Progress.

Men Are Individuals

The training program must recognize the fact that all men are individuals and cannot conform to a single pattern. By taking advantage of this fact, it is possible to lead a man's activities into the direction which will make him a complement to any group of individuals working on large problems. We do not find it advisable, nor do we expect our people to be experts in too many fields. We do not expect that any one man shall be responsible for all phases of chemical engineering requirements on any one project. Since our organizations are built up along the team-effort type, we must consider whether an individual, because of his analytical nature, will become the quarterback, or by his propensity for accomplishing large amounts of assigned problems will become the blocking-back, or whether his intuitive and interpretative senses will permit him to diagram the plays. We must find out in his training program what kind of an individual he is. It is not possible to expect that all members of such a team will be quarterbacks or blocking-backs or linesmen, but there is a place for each, all with proper recompense and personal satisfaction, provided each man is recognized as an individual and so trained and placed in the spot where he knows that he fits best.

Our Training Program

Now that I have set the objective of our program it is a simple task to explain how it is carried out. We use the tutorial system, particularly for beginners; and the strength of this system depends in a large measure on the quality, aptitude and personality of the men available on the staff. Each tutor is usually a specialist, thoroughly familiar with his field, who conducts the neophyte through a series of problems which illustrate the methods used. The trainee works alongside a succession of tutors spending from two weeks to a month with each tutor. Besides the tutors' courses, we have, of course, facilities by which the men can learn by actually doing. We usually prefer, in the idealized case, to begin a man's activities by allowing him to become familiar with petroleum processing equipment and its operation. This is done by placing him in experimental or commercial plants where he actually uses equipment, sees how it is maintained, recognizes its limitations and advantages, and obtains a better understanding of design problems. Engineers who have not had postgraduate training are more apt to be benefitted from operating experience than those who have received Doctorate degrees. Perhaps the Ph.D. knows the field of endeavor in which he prefers to direct his activities and may not need the extra period of development.

In either case, the engineer should be given tutorial instruction where he will have the opportunity to learn fundamentals that he did not obtain from his university training. Since a large percentage of our refinery investment is in separation processes, we try at some time during the earlier part of a man's career to give him a thorough training in distillation and extraction far beyond that which he receives in a university. We feel so strongly that a man cannot become a good chemical engineer in our industry without this background that as much as a year of training may be required to bring him up to the general level of knowledge we need in distillation and extraction. During the course of this early training he will spend considerable time learning to correlate and interpret basic data required for subsequent application. He will usually assist in preparing the technical data books to become familiar with the derivation of these data and cognizant of their usefulness and limitations. Once he has enough background and self-assurance, he will be assigned an increasing number of problems to do under the supervision of his tutor until finally he will begin to undertake process design work with a variety of associated assignments. Having reached this point the trainee is now in a position to move on to the field for which he is best suited and which he likes best.

This must be recognized as the idealized manner in which the early progression begins. There are, of course, numerous instances where chemical engineers will, to some extent, reverse procedures by working for fairly long periods in technical service work in our refineries, and their assimilation of both additional fundamental information and techniques will come at a later date. It must be recognized also that in those fields where chemical engineering represents only background knowledge, the comprehensive training outlined in this idealized case is not necessary. It is not necessary either for many positions open to those who prefer to confine their activities strictly to the operating field.

Typical Progress of Chemical Engineers

We endeavor to recognize each man as an individual, so it is not easy to generalize on how a chemical engineer progresses from a neophyte to operating technologist, specialist, executive, etc. However, Figure 1 is a typical example of the way in which an individual might progress in one of several directions. The chart will exemplify the opportunities and therefore the requirements for training chemical engineers to take over the various functions required of them in the petroleum industry. (*See* chart, p. *271*.)

Whatever the direction in which a man proceeds, every effort should be made to capitalize on his strong points and his compensation is therefore the highest that his ability permits. It does not follow that, because a man lacks administrative ability and is unsuited for supervising a group, he will be retarded if he has outstanding ability in another direction. This man will become ultimately a specialist and will receive both compensation and personal satisfaction equal to those who may be strong in the field of administration. Again, the executive engineer is a different type and one usually recognized at an early stage. He would be provided with opportunities for promotion and for learning in our program. In short, our training program is designed to aid, as much as possible, each individual in finding his proper position at the earliest possible opportunity.

THE TRAINEE'S VIEW

A. J. LANGE

Central Engineering Department,
J. E. Seagram & Sons, Louisville, Kentucky

I DON'T think there is any direct connection between the final product and the fact that the majority of the technical personnel in the distilling industry are men whose educational background is chemical engineering. Whether there is or not I feel quite fortunate to be one of this most versatile group. I am with a good company. Working side by side in our industry are electrical, mechanical, and industrial engineers. There are physicists,

chemists, mathematicians, architects, and bacteriologists. Also around are lawyers and the majors of business, economics, history, and the social sciences—a melting pot of knowledge which each shares with the company, his working companion and himself. Strangely, at the outset of his industrial career, none will pursue his educational endeavors to become expert in his field. That is part of my company's industrial philosophy and for a reason. The conventional educator produces, by indoctrination, a standardized graduate, a standardized reaction, fitting him for a traditional groove. Little or no provision is made to provide that graduate with tools so that he may cope with actual industrial and human problems and solve them.

With this problem in mind our company, under the leadership of H. F. Willkie, formulated a program which cultivated within its technical personnel the capacity for independent action, individual initiative and a motivation to seek and solve problems. The first approach is the development of the individual, not only in his technical capacity but also in all other aspects. This is accomplished through further "education" and something we call "planned experience." The result expected (and usually obtained) is a well-rounded person who, by reason of his breadth of cultural, scientific, sociological and economic outlook, is able to function in any environment, and as a result is a potential executive of the company, for all promotions come from within the company.

By "education" we mean the process of mental development acquired through study of subjects or facilities made available by the company and cooperating universities. By "planned experience" is meant utilizing progressive industrial activities as a function of employee development. Unlike educational studies which involve specific time intervals, planned experience finds new jobs or activities for the employee only when his own individual performance indicates that he is prepared and able to face new tasks. Each job experience gives the employee an opportunity to apply an increasing and varying wealth of knowledge to subsequent tasks he is to face. In sum and substance, the planned-experience program is just as flexible as the individual and includes all technical employees through the executive level.

Let us assume that several years ago a chemical engineer began his course in industrial education. He is still participating in it today. The first week of his employment may be compared to a freshman initiation week. Having been interviewed by the personnel, safety, and education directors, he is finally guided to a better-than-average looking office and there introduced to the plant manager. The latter is usually a young fellow with an uncanny ability to make you feel at ease immediately. Can you imagine the young engineer's amazement when he finds the manager knowing about his place of birth, childhood, and the schools and college he attended as well as his hobbies. Plant managers make it a point to know all newly hired technical men and keep a watchful eye on their progress. The manager also issues an invitation to the chemical engineer to visit and talk to him any time.

The next few days are confined to plant tours, films and lectures on company policy, quality, government regulations, safety and education. The education director has supplied the new man with literature pertaining to all phases of the operations and a blank notebook. With the latter he gives him instructions to roam around the plant making sketches of the flow of materials in each unit operation. Finally, after about a week he is assigned his first regular job. It's usually the toughest one in the plant. It doesn't require brains—but brawn. The idea is, of course, to discourage some fellows who thought their college degrees entitled them to something better than that and so they leave the company. Those who remain soon find that the rest of the operations are comparatively easy physically and also require the use of their brain.

To make sure that the engineer is not a robot performing a mechanical function only, once every three weeks, when on the day shift, he meets with his supervisor, the education director, and the other members of the shift in a classroom in the plant immediately after work. A written examination is presented which involves the theoretical aspects of the operation on which he is working. Whenever he changes to another operation quizzes pertaining to that particular function, are given. If he remains on one job longer than three weeks, it is always a different examination. After each interrogation the balance of the hour is used by the supervisor to give a talk on some problem or phase of operations.

A. J. LANGE, since graduation from the University of Dayton with a B.Ch.E. degree in 1942, has been employed by Joseph E. Seagram & Sons, Inc., Louisville, Ky. During that time his training and development have been at six plants in twelve various positions dealing with production, maintenance, utilities, construction, industrial sanitation, industrial education, and presently chemical engineering in the central engineering division.

Each month the technical operator's notebook has to be submitted to the education director. He checks it thoroughly, adds his comments, sends it to the department head who reads it and returns it to the operator. In the meantime the shift supervisor will also interview the engineer on the job once every two weeks: Have you any complaints? Do you understand your job thoroughly? Why do you do this? What part does your operation play in the over-all manufacturing process? Do you have any suggestions of doing it different and better? What is the viscosity of the mash in the cooking tube? What would you do if an emergency shutdown would occur?

This method of on-the-job training is continued through all the unit operations such as milling, cooking, fermentation, distillation, evaporation, and drying.

To help keep the mind active and open to operational changes, university courses are given by university instructors. These are held at the plant after work. Participation is voluntary. They are all two-credit hour courses and each semester the prospective student has a choice of three. The courses are divided in two series, industrial and cultural. The industrial courses include:

Bacteriology
Public Speaking
Unit Operations
Fundamentals of Accounting
Creative Writing
Transportation Economics
Business Law
Marketing
Statistics
Public Relations
Industrial Relations

The cultural courses are:

International Relations
Music Appreciation or History of Music
History of Painting
The Urban Community
Economic Geography
Psychology
Genetics

Regular tuition is paid for any of these courses by the student but on the basis of grades, a refund is obtainable (A—100%, B—75%, C or D—50%). If the employee doesn't like any of the courses being offered at the plant, he

could attend the nearest university, take any course he wished and still obtain the same refund.

After about 6 or 9 months within the planned-experience program the engineer has been in enough operations to qualify for the "Distillery Examination." This test is quite comprehensive, covering every phase of the production department. An additional requirement at this time is to submit a revision of a production procedure or unit operation so that some one following will benefit by his experience on that particular job.

Having passed the basic test so to speak, and possessing the necessary qualifications, the engineer may be enrolled in the Pre-Supervisory Training Class. Problems of supervision of every conceivable nature are presented, discussed and it is hoped—solved. The meetings are held once a week for one hour during working hours. Presently the class is limited to eight and may be allowed to drop to six, depending upon future supervision requirements and sufficiently developed men.

In addition to personnel management problems, films are presented, plant executives speak to the group and the members themselves give talks and hold panel discussions. This program repeats itself about every 18 months, by which time a completely new group is usually in attendance.

Once the chemical engineer has achieved supervisory status he may hold that position at various times in the production, maintenance, engineering, or instrument departments, gaining experience as he goes along. Regardless of which department he may be a member he is still training. Once a week he participates in supervisory meetings and must answer quizzes monthly on government regulations pertaining to the distilling industry, fundamentals of distillery practice, the distillation of alcohol, and problems on management. He also is asked during this period to participate voluntarily in civic functions.

The next steps up the ladder are those of assistant to department head level. The planned experience and education programs are still in force. The chemical engineer may be a department head in the utilities, production, warehouse, or bottling departments at some time or another. Once his training is completed here there are usually two choices: on up the ladder administratively to assistant plant manager or the central office division of engineering and research. Finally the chemical engineer can be a chemical engineer and because of his educational background as well as overall training experience, he is the best there is to be had. Perhaps it may be said that at this point his training really begins.

BASIC CONSIDERATIONS IN DEVELOPING ENGINEERS

J. C. McKEON

Manager, University Relations, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

THE most crucial problem facing American industry is the development of leaders for the future—leaders in both the technical and management areas. Leaders of the future will be drawn from the ranks of professionally trained men. The type of leadership we can expect will depend on the quality of the preparation young men are receiving in the colleges and in industry. The education and training of the young engineer is, therefore, a joint responsibility of industry and the colleges. True, the engineering colleges have been preparing potential engineers for industry for many years. Moreover, industry is providing training for the advancement of the college graduate. However, I have in mind something of even greater significance to the engineering profession—development of a new attitude toward our mutual responsibilities as partners in education and professional growth of the engineer.

The theme, industry-college partnership, is challenging. I should like to suggest that we include a third member on our team. I refer to the engineering societies. Organizations such as the American Institute of Chemical Engineers are in an excellent position to exert a constructive influence at both the national and local levels. As in any partnership, each member has much to gain if the venture proves successful and unlimited liability if it fails. If we can become as concerned about designing programs for developing men as we are about designing a quality product, our success is assured.

J. C. McKEON as manager of university relations, is responsible for the Westinghouse advanced educational programs and general relations with the colleges. He is active in engineering and professional societies serving as a member of E.C.P.D. committee on professional training, A.S.M.E. education committee, A.S.E.E. general council and A.S.E.E. relations with industry executive committees. Prior to joining Westinghouse, nine years ago, Mr. McKeon was associate professor of industrial management at the University of Tulsa. He received both his Bachelor's and Master's degrees from Penn State.

What are some basic considerations in designing effective programs for engineers in industry? Let's get down to basic elements since they are applicable to all companies, large and small. *How* a thing is done is important, but there are many ways of reaching the same objective, and the specific methods employed will depend on the size and type of organization of the company. Of greater significance is *what* should be done and *why*. The *why* is particularly important. If we understand why we are doing a certain thing, we can keep abreast of changing conditions and continue to improve our methods. The need for training and education in industry becomes apparent when we realize the gap which exists between the graduating senior and the status of a full-fledged engineer.

The Transition

Since the beginning of the Technological Revolution, industry has become increasingly technical and complex with a resulting high division of labor. The independent craftsman of yesterday has been replaced by the scientist, the design engineer, the accountant, the labor lawyer, and other specialists.

While the craftsman of former years grew up with the business, the college graduate of today steps into a strange organization at a relatively high level. He has had no opportunity to understand through long association the methods and operations of the concern. During his first few years with a company, the young engineer is finding his place in the organization, attempting to under-

stand himself, and shaping his professional goals. Frequently, he is establishing his family and generally his salary is modest. Closing the gap between his experiences on the campus and the realities of earning a living in a complex situation is not an easy task. The young engineer needs a helping hand in making the transition from directed development to self-development.

Division of Responsibility. Specialization in industry has led some people to the erroneous conclusion that the colleges should train specialists. This is a serious misconception. Actually, the best education for industry is a sound foundation of fundamentals. With a thorough knowledge of fundamentals and a skill in their use, the engineer can handle new problems of a specialized nature. Specialized jobs in industry cannot be learned in college, but only through years of experience. Moreover, education in fundamentals gives the young engineer greater flexibility in employment and subsequent promotion. One's career often takes unexpected turns. It is the colleges' responsibility to train for a career rather than for a job.

Progressive management is looking for men with a high potential in the technical and management fields—men who are well grounded in engineering fundamentals and who have the personal qualities essential to teamwork. Specifically, industry is looking for men who have:

1. Technical competence.
2. Desire to get ahead.
3. Ability to deal with people.

The employer must provide the industrial know-how and the specialization required of the job. But management must do much more than this. Management must be concerned with the development of the whole man.

While each partner has a leading part to play in its respective area, the other partner must play the supporting role. Precisely what are the essential features of a good development program for the engineer in industry?

Requisites for Development in Industry

Proper Environment. The first requisite for effective development is a favorable atmosphere in which to grow. This means an enlightened management which fully realizes that of all the ingredients going into a successful business, trained personnel are the most important. It means a management which uses a man's abilities at the highest possible level and at the same time provides opportunities for his further development. In recognizing the importance of attitudes in the professional attainment of the young man, industry must not be unmindful of the role played by management's attitudes at all levels. One of the best ways to develop professional attitudes is through association with a boss who has a healthful outlook toward the job, our social institutions, and life in general.

Selection and Initial Training. The best of training programs will not bring the desired results unless competent men are available for such training. The selection of the right type of men for the company is, therefore, high on the list of requisites. Men employed at the colleges for jobs should be selected for their potential rather than for their ability to become immediately productive. It is to these men that management must look for future leadership. Careful screening of candidates is essential since a college diploma is not in itself evidence of fitness for a particular company. Progressive management realizes that errors in screening applicants not only result in the employment of misfits who prove costly in terms of turnover and employee dissatisfaction, but deprive the company of good men who will be needed.

There is little use of recruiting outstanding men unless some provision is made to give them the orientation and basic training they need to do a job. In addition to becoming acquainted with the personnel, organization, and policies of the company, the graduate needs work experience in the different aspects of the company's operations so that he may learn firsthand the avenues of opportunity which are open to him. For the most part, the recent graduate is not certain of the type of job for which he is best suited. During his first year or so, a series of work assignments of several months each will give him a better understanding of such functional fields as research, design, manufacturing, sales, and purchasing.

When a college graduate joins a company, he is making an investment of his time and talents in that organization. Accordingly, the new recruit has a right to expect his company to make an investment in his development.

The organization with which I am associated has long recognized the importance of the selection and training of talent. Through the efforts of George Westinghouse and B. G. Lamme, the company took an early lead in recruiting engineering graduates at the colleges and training them for responsible positions. In the past half-century, we have recruited more than 17,000 graduates in electrical, mechanical, and chemical engineering—in fact, in all branches of engineering and science. Our initial training program is known as the Graduate Student Training Course. Its objectives are to give the recent graduate an understanding of the company's organization and the diversified activities open to him, to teach him methods of applying fundamental principles to the solution of industrial problems, and to assist him in finding the type of work for which he is best fitted by virtue of his educational background, aptitudes, and interests. In brief, it is a process of matching men and jobs and providing each man with the tools he needs to move forward. These objectives are accomplished through a series of coordinated work assignments, technical and professional conferences, and individual counseling in a well-defined program which extends over a period of approximately one year. This type of program gives assurance that the young engineer will receive personal attention from a sympathetic supervisor and will not become lost in the organization.

Continuous Development. But orientation and initial training are not enough. There is need for follow-up training on an informal basis as the engineer moves along in his career. The key to good work is job satisfaction. Management engineers have found that satisfaction depends, in a large part, on whether the job draws on all the professional employee's talents. In the past, too much of the Procrustean philosophy has been applied. Procrustus, as we recall, was the legendary highwayman of Attica who tied his victims upon an iron bed and stretched or cut off their legs to adapt them to its length. Too frequently, men and jobs were thought of as round or square. But men are neither round nor square—they are many different shapes from the standpoint of aptitudes, abilities, and interests. Flexibility in arranging jobs, so that activities are fitted around the man rather than forcing him into a mold, is advantageous when dealing with the mature engineer both from the standpoint of productivity and morale. Research directors have found that by giving the scientists a percentage of their time to work on projects of their own has paid off in scientific developments and job satisfaction. There is need for more careful study of individual aptitudes and interests, together with a more intensive analysis of job requirements.

Job rotation on the higher levels broadens a man's experience and assists materially in developing leaders. A promotion system based on individual per-

formance together with insurance and pension plans contributes to the employee's peace of mind and thus creates a favorable condition for professional growth.

Education for Leadership. Management must be interested in maintaining an ascending growth curve through self-development on the part of the young engineer. The engineer must not only be a useful member of the industrial team, but he must also be a good citizen. One method of keeping the young engineer mentally alert and moving forward is through well-planned educational programs. Some of these may be aimed at increasing his technical competence while others at broadening his social knowledge. Industry's educational needs are quite diversified. Here are some of the areas requiring attention:

1. After initial training, a portion of the engineering graduates find their places in such functional fields as research, development, design, and manufacturing engineering requiring advanced study in mathematics, science, and engineering.
2. Others, who find they are best fitted for sales engineering, production, purchasing, and business functions, may benefit more directly by supplementing their engineering degrees with courses in economics, marketing, finance, and law.
3. Certain individuals in the foregoing groups will demonstrate a capacity for handling people and will need executive development as part of the grooming process.
4. A few will have the talents to rise to top management and will need a broad foundation in business management.

All members of the foregoing groups need a better command of the tools of communication, both the written and the spoken word, and the ability to sell themselves and their ideas. Moreover, it is essential that they have an understanding of the business and the social institutions under which they live. Both industry and the colleges have responsibilities in these educational areas.

One of the most fruitful areas of industry-college cooperation lies in providing programs of graduate study for engineers engaged full time in industry. Industry employs many graduates on the Bachelor's level who are well qualified for graduate work. A sizable group goes into activities which require a knowledge of advanced fundamentals. For a number of years, certain universities have successfully offered late afternoon and evening courses. The value and soundness of the programs are generally recognized but, unfortunately, the practice is not so widespread as it should be.

Not only does industry have the problem of preparing engineers for key technical positions, but also of developing men for management. Forward-looking management is giving this matter serious thought and is doing something about it through careful planning. Any plan, to be successful, must provide for finding and developing talent within the company. Progressive management has analyzed its future supervisory requirements, completed a personnel audit, and planned some form of management development.

There are, of course, many facets to management development. Some of these can be polished through job rotation and training within the company while others require outside help. The universities can make a real contribution in this area of personnel development, during the engineer's early training, by offering courses in business and the social sciences, and later on when he is being groomed for more responsible management positions.

Certain of the Schools of Business and the Industrial Relations Sections of the universities, as well as the Engineering Extension Services offer short courses in various phases of industrial administration in cooperation with industry. Of particular interest is the Advanced Management Program of the Harvard Graduate School of Business Administration, and Management Problems for Executives sponsored by the University of Pittsburgh. These courses run for twelve and eight weeks respectively on a full-time basis on the campus. Participants are selected by the companies who pay the salaries and expenses. Both programs have proved eminently successful and, as a result, are attracting top-flight men.

However, only a relatively few engineers have the opportunity to take these courses. Many employees have in-company educational programs available or may enroll in evening classes at a near-by college. An increasing number of technically trained men feel a need for a better understanding of our business economy, labor relations, law, and finance, or possibly psychology, sociology, and philosophy—all of which are significantly related to the formulation of the individual's social and professional concepts. Too frequently, however, the courses are taught on the sophomore level and, thus, offer little to stimulate the man in industry. The colleges can be of real assistance in designing courses in these areas for the mature person in industry.

Professional Activities. Engineering societies and other professional groups have a significant role in assisting the engineer plan his self-advancement program. Industry should encourage the young engineer to take an active part in the programs of his local engineering society. Participation in these activities engenders a sense of belonging and promotes a professional consciousness. An esprit de corps should be fostered in each society, but not to the extent that it blinds its members to an appreciation of the mutual advantages of working with all professional groups and other segments of society.

Through discussions with members of his own local branch, the engineer gains a deeper understanding of the ethics of his profession. The preparation and presentation of technical papers and reports not only build self-confidence, but also generate further interest in expressing himself effectively, and in learning more about techniques of communication. Such activities give him recognition both within his company and in his community.

The Small Company

"But what about the small company?" many will ask. The basic elements outlined in the foregoing paragraphs are as applicable to a small company as they are to a large organization. Small companies need a training and development program as much as a big outfit, but it must be tailored to fit their needs. Accordingly, it is a mistake for a small company which is inexperienced in training to adopt the programs and methods of a large business which has been training-conscious for many years. It is better for a small company to set down a few practical objectives and reach an agreement on how those objectives can be attained. All that is needed is the active support of top management and someone who is interested in the young recruit and his professional development. The important thing to remember is that training and development are important functions to be performed irrespective of the size of the company.

Achieving Better Understanding

Mutual understanding is the key to industry-college cooperation. In instances where the representatives of the colleges and industry sit down at a conference table and discuss their problems, we find real cooperative effort. Through such discussions, each side gains an insight into the problems of the other, and a realization of their joint and separate responsibilities. If the colleges are to continue to turn out competent men, they must have the active support of industry. By the same token, the colleges' responsibility for education cannot end when the student

leaves the campus for his first job in industry.

There are many ways in which industry can promote teamwork with the colleges. They include summer industrial experience for professors, arranging joint industry-college seminars at industrial plants, joint graduate study programs, providing top-flight engineers and scientists as evening graduate school lecturers, selling laboratory equipment at attractive discounts, preparing engineering problems and material for the classroom, and sponsoring scholarships.

Westinghouse is interested not only in the recruitment of high potential men at the colleges, but we believe that we have a responsibility to assist the colleges in finding particularly talented young men and women and helping them secure an education. The George Westinghouse Scholarships at the Carnegie Institute of Technology, the Science Talent Search, the War Memorial Scholarships, and the 4-H Club Scholarships which are open to high school seniors have provided recognition and assistance to a large number of talented young people. An extensive program of scholarships and fellowships in engineering, the physical sciences and management, as well as several professorships are maintained by the Westinghouse Educational Foundation. More than 600 employees are enrolled this semester for graduate work at the seven universities with which the company cooperates through its Graduate Study Program. Since the inauguration of the plan with the University of Pittsburgh in 1927, more than 6,000 employees have registered in the programs at the seven universities, and many have received advanced degrees.

Opportunity and the Individual

Opportunities open to the competent engineer are limitless. America has the capacity, the jobs, and the resources to make the next ten years the greatest decade of prosperity this country has ever known. How? The answer is productivity through machine power. The colleges can provide a well-integrated engineering education. Industry can provide the training, the encouragement, and the recognition necessary for advancement. But each individual must assume the major share of the responsibility for his own advancement since success depends on the man himself.

TRAINING FOR PROFESSIONAL COMPETENCE

WEBSTER N. JONES

Dean, College of Engineering and Science,
Carnegie Institute of Technology,
Pittsburgh, Pennsylvania

EVERY individual who chooses chemical engineering as a profession should aspire for professional competence, and every mature chemical engineer—whether as teacher, as engineer in industry, or as a member of A.I.Ch.E.—should help him achieve it. Training for professional competence is not only a personal matter with each of us but also an opportunity for each of us to advance our profession by aiding the young men who follow in our footsteps.

I know from experience that teen-age boys who have entered a school of engineering do not have a clear idea of professional competence. How could they without formal training or practical experience? The college professors have the duty of indoctrinating the young men into the profession. Industry has the task of affording the young graduate the opportunities of attaining professional competence. The A.I.Ch.E. must determine the standards essential to professional development and bring them to the attention of the individual, the college, and industry. There are various levels of professional competence. I would set the lower limit as the qualifications for the Active membership grade in the A.I.Ch.E. The upper limit knows no bound.

The great expansion of chemical industry is attracting some of the nation's brightest young men to our profession. This raises an important question: Whose responsibility is it to see that these young men will attain full professional competence in the years to come? Before we can answer this question, we must know what the essential influences are that will enable the college graduate to achieve ultimate professional competence. There are four major influences: the native inherent ability, personal characteristics, and desires of the individual; the formal training that the educational institution provides; the internship which industry offers the young chemical engineering graduate; and the educational, ethical, and technical standards established by A.I.Ch.E.

Let us first discuss the responsibility of the young engineer. It is my conviction that the primary responsibility to make the most of his professional life rests squarely on the individual. However, it is my thesis that we—the colleges, industry, and the Institute—do not do enough to help him, particularly in the critical years following graduation.

What should the division of responsibility be between the college, industry, and the Institute in the training of an engineer? In accordance with custom of long standing, the American student prepares himself for professional work in engineering by means of formal education in college; and that is followed by a period of on-the-job training in industry. Formal education cannot continue forever—yet, the engineer should grow professionally during his whole life. It is practical, then, and economically sound that the college should direct its education primarily toward helping a man to develop the capacity to use fundamental knowledge and to learn from experience; this leaves for industry the responsibility for training the graduate in much of the specialized knowledge and procedures—commonly called "know-how"—that he will need in his work; and both industry and the colleges must work together in the Institute to encourage the highest professional standards and continuing interest in technical development.

WEBSTER N. JONES has been dean of the College of Engineering and Science of the Carnegie Institute of Technology, Pittsburgh, Pa., since 1932. A Ph. D. from Harvard, Dr. Jones has been instructor at the universities of Purdue, Harvard, Maine, Missouri, Radcliffe College and assistant professor of chemistry at the University of Montana. He was also associated with the B. F. Goodrich Co. as research chemist; manager, General Chemical Labs., then technical superintendent, and general superintendent of the processing division. Also a member of many technical societies and a writer on engineering subjects. Dr. Jones was President of A.I.Ch.E. 1939-40, and a Director 1931-33, 1935-37.

Let me now discuss with you what the college should do. I shall illustrate by telling what has been accomplished during the past few years on our own campus.

The Carnegie Institute of Technology has been vitally concerned with this problem. We have been revising the curricula in an attempt to find better ways of teaching fundamentals so thoroughly that the student can readily apply them to specific situations, and to find how best to apply what he has learned from previous experiences. Our educational philosophy has been put into words—into what we call "The Carnegie Plan of Professional Education in Engineering and Science," as follows:

"The aim of professional education at Carnegie Institute of Technology is to equip students to go on learning after graduation and to grow throughout their lives in professional and personal stature and in usefulness as citizens. Carnegie does not seek to train students to be professional practitioners at graduation but rather to educate them so that they will become professional men of full stature.

Instruction is therefore planned to help each student acquire the following:

1. Thorough and integrated understanding of fundamental knowledge in the fields covered by the student's curriculum, and the ability to use this knowledge.
2. Genuine competence in the orderly way of analytical thinking which professional men and scientists have always used in reaching sound, creative conclusions; to the end that after graduation the student can, by such thinking, reach his own decisions in his profession and as a citizen.
3. Ability to learn for himself with scholarly orderliness; so that after graduation he will be able to grow in wisdom and keep abreast of the changing knowledge and problems of his profession and the society in which he lives.
4. The philosophical outlook, breadth of knowledge, and sense of values which will increase his understanding and enjoyment of life and will enable him to recognize the human, economic, and social problems of his professional work; and the breadth of ability to use his professional powers in dealing with these problems and those he will meet as a citizen and a person.

Instruction is focused upon fundamental content useful in later learning, rather than upon the amassing of particulars of knowledge and technique that can better be learned at the time of use. In advanced courses, emphasis is also placed on using the fundamentals learned in earlier courses."

This is the plan we are following at Carnegie. We do not claim that this plan of education is the last word in a college's contribution to the training of an engineer for professional competence. Some plan is required—yes—but of even more importance is the quality of the teacher, the quality of the student, and the way in which they work together. The teacher must want to teach men, not alone subject matter. The student must want to study, and must be made to realize that he learns only from what he himself thinks and does.

I have discussed what education can do for the young chemical engineer. Now, what about industry?

I am particularly interested in industrial training programs because of my own experience. For many years, as an employee of a large rubber company, I was engaged in the selection and training of technical men. It is a source of great personal satisfaction to me, that many of "my boys" have risen to positions of distinction in engineering, research, production, purchasing, and sales. Among them are plant managers, research engineers, directors of purchases of the parent company and several vice-presidents, and even a president of the company's subsidiaries. Naturally, some of them for one reason or another, myself included, did not remain with the company. Whether they remained with the company or not I am very proud of them because of their technical and business achievements, their civic-mindedness and, above all, their loyalty to each other, and incidentally, to me.

What was accomplished there was not unique, nor should it be. Management should realize fully the potential value of in-plant-training courses, and should avoid training a young engineer for a particular job. Management must be convinced that job training is not enough; we must have *man* training to the limit of the man's capacity and potential usefulness. The broader the work experience a trainee is given, the better for the man and for the company. I understand that this is more difficult now than formerly because of labor union regulations. This problem should be resolved by negotiation between top-management and union officials. Top management should not default its leadership in this important activity. The development of professional competence in its engineers is not a charitable nor a philanthropic undertaking for industry; it is a sound investment, sometimes in immediate return and always in the long pull, for the greatest asset of any company, large or small, is its personnel.

Who should guide the formal in-plant-training program? The program should be led by a professional engineer who is familiar with all the activities of the company and with the men who direct them. He should be vitally interested in young men, should be an excellent judge of them, and should be capable of winning their respect and confidence in both technical and personal matters. The responsibility of developing the aims, scopes and procedures of the training program should be in his hands and he should recruit men for his company. In a large company he will need assistants, who should be chosen with characteristics and training similar to his. Let's call him an "industrial dean."

Selection of personnel capable of achieving full professional stature is one of the most vital responsibilities of the industrial dean. He cannot do it by means of completed application forms and 15-min. interviews. He will find that it pays to maintain contacts with faculty members and college personnel officers from whom he obtains recruits. He may wish also to encourage his company to employ college men during the summers following their sophomore and junior years to determine their fitness for employment. The ability to choose personnel of promise is a rare gift and is not necessarily confined to members of the staff of the personnel department. He may be fortunate enough to find several persons in his company who are capable of making intelligent selections of new employees. When he hires young engineers, it is important that he know fairly accurately how many men are to be retained, so that his company does not accept more young men than it needs only to be forced to release the excess later to the detriment of the reputation of the company and the undermining of the morale of those released.

During the in-plant training there are many significant aspects that should receive attention. The trainee should be rewarded for work well done either by an increase in pay or by an increase in responsibility. A young engineer prefers an increase in responsibility to an increase in compensation if he is on a routine job where his chemical engineering training is not being used adequately. Furthermore he knows that an increase in responsibility is the means to an increase in salary.

Perhaps the most significant aspect of training is arranging manpower so that the beginners are intimately associated with those who are skilled and possess the rare ability to teach others. Such relationships do occur in industry—perhaps more frequently by chance than by design—but everything should be done to foster them.

The job of the industrial dean is not finished when he has given the trainee a broad experience in the company. In fact, he has other duties to perform, enough to fill a thick volume, were I to enumerate them. However, I wish to mention a few more: he should encourage the trainee to join a national professional society and to take an active part in the local section meetings; to study on his own time and to attend evening classes if this is possible; to

become a registered professional engineer; and to take an interest in, as well as a part in, civic affairs of the community.

I have discussed what colleges and industry can do separately for the young chemical engineer. Now, what is our Institute doing?

In 1908, 100 industrial chemists met in Pittsburgh and organized the American Institute of Chemical Engineers. I dare say that not one of the charter members would have predicted that by 1949 nearly 100 schools of engineering would be providing specialized education for 22,000 chemical engineering students each year; that more doctorates would be awarded than in any other branch of engineering; and that the roster of the Institute would number 9,758: 3,667 Active members, 497 Associate members, and 5,594 Junior members.

The Institute is deeply interested in the young engineer. It has fostered the organization of student chapters and has encouraged professional competence of students by awarding prizes. However, more attention could be paid to the Junior membership which exceeds the Active membership by fifty per cent.

There is one activity that has had a significant influence on chemical engineering education and that is the work of the Accrediting Committee. The Institute was the first of the engineering societies to become interested in accrediting schools. As a result of long and arduous study it has established criteria by which curricula are judged. The accrediting is carried out in cooperation with the Engineers' Council for Professional Development. As of September, 1948, of the 83 curricula submitted, 41 had been fully accredited and 15 provisionally accredited. The accrediting procedure is most comprehensive. It also provides for reinspection at 5-yr. intervals. This keeps the colleges from assuming a satisfied air.

And now, having discussed in turn what industry, the colleges, and the Institute are doing and can do, I wish to emphasize, in closing, the necessity of full cooperation of all concerned in this vital problem of aiding the young engineer to achieve professional competence. Training for professional competence, as I have said, depends on—the individual, the college, industry, and the Institute. It will be only by continued cooperation and joint efforts that the future of chemical engineering and the future of our country will remain bright.

EDITOR'S NOTE: *Discussion was started on the basis of written questions collected from the audience during the foregoing papers . . .*

Chairman Manning: Mr. McEachron, what is the incentive for good performance on the part of the trainee in a training program, and what is the penalty for poor performance defining "performance" as the ability to assimilate and use the information presented?

K. B. McEachron, Jr.: The penalty for poor performance or the incentive for good performance is not much different from that in college. The opportunity for permanent placement in the company at the conclusion of the training program is very much different between those men who have made an outstanding record and those who have just gotten by. The supervisor makes a rating on each man and discusses it with him, and at the end that rating and the rating in the advanced classes are available, together with any other information we have, such as college record, to the men in the company interested in placing him permanently.

Actually, in a few cases we release employees from the company. We don't guarantee anybody that we will keep him on indefinitely. However, I think the point that Dr. Jones made is important: We don't employ people with the idea that we are going to release them at the end of training; anyone we employ for the training program we expect to keep. When we must release a person, we consider it an error on our part—we should never have recruited him. We don't over-employ.

Chairman Manning: Mr. McKeon, in view of the time limitations within any college curriculum and the admitted necessity of emphasis on fundamentals, is it logical to give further fundamental courses or more so-called humanity and cultural courses?

J. C. McKeon: Mr. Chairman, I think industry can point out what is required in the industry, but I don't think we can tell the colleges how to teach it. We don't know enough about college curricula. I don't want to be facetious, but the question posed alternatives, and I would say both.

I think we have to wring the water out of the fundamental program and be sure it is fundamental. If you check over your program you may find there are a number of courses that are application courses. The other point is, of course, to bring in more fundamental courses in the humanities and social sciences. I suppose the answer is to have a good balance.

Chairman Manning: What does the panel think of the student cooperative program of some schools as an instrument through which industrial requirements can be carried out?

K. B. McEachron, Jr.: I think the cooperative program is a good way in which to achieve our objectives in industry. In our company we are engaged in such a program in three institutions. However, I think it is wise to emphasize that we don't feel it desirable to have all of any one kind of education in the country. For instance we experimented with undergraduate education within the company back in the Twenties. We concluded it was unwise to do that sort of thing because we have a great advantage in diversity and types of experience by employing people with many different backgrounds. So although we are deeply interested in the cooperative program we are by no means of the opinion that every school, or the great majority of programs, ought to have a cooperative program within them.

J. C. McKeon: I might add that each individual can develop his own cooperative employment program, along the lines of Dean Jones' suggestion of summer employment.

Chairman Manning: Mr. Johnson, does your industrial training program vary for the chemical engineering graduate and the petroleum engineering graduate?

A. J. Johnson: There is no essential difference. As a matter of fact, in our company men shift from the chemical to the petroleum end. I must admit that in the early stages of a man's development his own self-satisfaction is the most important thing to us. As I mentioned, I don't believe we can look at any group of men other than as individuals. Hence you will see a man direct his activities in one or the other direction, petroleum or chemistry. As soon as we recognize that, we make an attempt within our program to give him the maximum of training, experience and of course opportunities, for progressing in that field which he desires.

We have a dean, as referred to by Dean Jones, the Dean of the University of Petroleum, at least our advertising department so calls him, and that is Dr. Souders. He essentially is in charge of our formalized training of young chemical engineers. As long as they are with Dr. Souders, undergoing the formalized training, he makes no differentiation between the chemical engineers going into the chemical program and those going into the petroleum program.

Chairman Manning: Mr. Lange, does Seagram's provide for the young engineer to have leave of absence for graduate work, and does he get a refund on graduate study?

A. J. Lange: No. The company provides quite a few fellowships each year, which are up on a competitive basis, so to speak, and if anyone does wish to go to school to obtain his graduate

degree, he writes the letter to the plant manager, who will in turn forward that letter for consideration by the Fellowship Committee. However, since the three large plants within the company are close to universities, quite a few allowances are made in order to obtain graduate degrees while working at the same time. The Baltimore plant has an arrangement with the University of Maryland; the Lawrenceburg plant with Purdue University, though quite a few go to the University of Cincinnati; and the Louisville plant is affiliated with the University of Louisville. So anyone who wishes to do graduate work and has not received a fellowship may pursue his education in that way and he is refunded in that manner. Now the fellowship comprises full payment of tuition, fees and books, as well as the regular salary.

Chairman Manning: How many engineers are in training at any one time, in any one group?

A. J. Lange: The engineers begin their training of course from the day they are hired and, as I have mentioned before, they remain in that training at all times. Job changes, always present new problems which they are expected to solve. Actually training wouldn't cease until the engineer would leave the company.

Chairman Manning: How many groups have gone through your training program?

A. J. Lange: That is difficult to say, because the training program is continuous and everyone is in the program, so you might say there is sort of renewal of the program each year when a new group of engineers is hired for the various plants in the company. The initial group of engineers hired each year has varied from 5 to 30 over the past 10 years.

Chairman Manning: A question for the panel:

Training programs have been popular and therefore presumably successful with a number of large organizations. We hear little about such programs in small organizations. Is it inherently practical to conduct training programs in small organizations? Are there any characteristic distinctions peculiar to them as opposed to the large organization?

K. B. McEachron, Jr.: I would like to have that one. I think that it is completely possible for a small company to have a better training program than a large company. They don't need a large extensive training program, all they need is someone interested in the young fellow, someone who will see him along, see that he gets work experience in the different phases of the work. And of course, most important, top-management support.

I think many of those fundamentals that I tried to mention today are just as applicable to the small company as the large one. True, the small company has to have a different setup, but if someone takes the young fellow under his wing, he will get the background he needs.

Chairman Manning: Do you feel a man with a Ph.D. training has a distinct advantage, in that he can first, skip the training period completely; second, have the inside track to positions of responsibility; and will probably therefore advance further?

That I think will bring on a debate, because I don't believe the experts will admit he should skip the initial training period.

A. J. Johnson: It is my feeling that a man coming into an organization with a Ph.D. has two advantages. One is his maturity, and second, possibly because of the maturity he has a better idea of what he would like to do. I feel the single most important part of any training program is to relate the man's own ideas of his ability with those ideas that you have of his ability.

When a young man is first hired, if he is not a Ph.D., he needs more opportunity in which to have judgment passed on him. After this longer initial period, he then tends to equal a Ph.D., who has had the opportunity, through his additional training in school, to give mature thinking to what he wants to do. But in either case I think both of them need the training course, the Ph.D. needs less of it, but the Bachelor must have more of it.

Chairman Manning: Mr. McEachron, do you find chemical engineers are more or less versatile than other engineers in their technical ability to fit into your company? What are their blind spots or other obstacles to rapid progress?

K. B. McEachron, Jr.: That is a sort of inclusive question. I am not a chemical engineer by training, but only somewhat by experience. I think I would say that the chemical engineer potentially is the most versatile, as far as the field of engineering is concerned. I think I am right in this statement, that it may be at least in part because the chemical engineer frankly is worked harder in college than most other engineers. I think that there is a definite sorting process going on. You know what happens when the engineer successively goes downhill trying to find a course he can get through and still call himself an engineer. That's my impression, that the chemical engineering curricula on the average require the most work.

With respect to the blind spot. I think the largest blind spot—and probably this is true of most every kind of engineer—is his attitude concerning the work he is going to do in industry. He limits himself by the fact that he doesn't, or thinks that he can't, do the particular job that may be asked of him. He may have the ability but he doesn't think he can do it, or it doesn't agree with his idea of, let's say chemical engineering or electrical or mechanical or whatever it may be. The man needs to have versatility up in his head, in his mental attitude toward the problem, as well as in his training.

Chairman Manning: Mr. Johnson, under your tutor system of training, do the tutors have any other jobs with the company besides tutoring?

A. J. Johnson: I'll say they do. As a matter of fact, I don't think a man can be a good tutor under a system like this if he has to devote his entire time to tutoring. He cannot possibly be the specialist we expect him to be. As we all know, chemical engineering is a rapidly moving profession and to be truly up to date he must spend the bulk of his time keeping up to date, advancing with the profession, and have only a part of his time available for the tutoring job which he must do.

Chairman Manning: Mr. Lange, what is the purpose of the cultural educational program in collaboration with local schools for the trainee? Has this program been established because it was found that the young engineering graduate was steeped too much in technical subjects alone?

A. J. Lange: I don't think the innovation of the cultural courses was meant as an insult to the engineer. However, the amount of mathematics and science, with which he is primarily concerned, does not give him a sufficiently broad view of life in general. For that reason the company has inaugurated various courses to develop a cultural background, such as in the appreciation of music and the history of painting.

A. J. Johnson: I would like to know why this cultural training permits a man to design a better unit?

A. J. Lange: First of all, the pursuit of a cultural course is voluntary. It is assumed that the qualifications that an engineer should possess plus the industrial training that goes on within the plant, plus the industrial training that takes place in the university, would result in a combination of engineering knowledge and an appreciation of the arts which would make him a better man as well as a better engineer. Does that answer your question?

A. J. Johnson: Well, in part. But it

is simply that I feel a man's outside activity, beyond his professional activity, should be left strictly to himself.

A. J. Lange: It is.

A. J. Johnson: And when you emphasize the benefit of it, and add the statement that it is entirely voluntary, I can only say that it agrees with my principles. It leads to the thought that a man should have cultural activity. Personally, I like to do coloring, and if any other man wants to do likewise that's all right.

A. J. Lange: There is no tuition, of course, and no fees of any kind involved other than the materials necessary in our recreational courses. We have courses in home mechanics and radio where we buy the parts and the individual under proper tutoring assembles the radio. For those who desire, we also have water color painting, which in a sense may be cultural. Also we have courses in photography and applied arts in which anyone may participate. Strictly voluntary, of course.

Chairman Manning: Mr. McKeon, is it true that some universities are discouraging out-of-state personnel investigators? And if so, how? What is your policy on that?

J. C. McKeon: I think the politicians have something to do with that. In talking to the deans, you find they want their men to go wherever they find the best opportunity. But in talking to the politicians, there is the statement, aren't we losing the students to the North and East, what can we do to keep them at home?

I think it is a shortsighted policy. Our company hires from all accredited engineering colleges. They all go on the payroll here at Pittsburgh and receive some training. But they find their way to Alabama, to the West, and so on. It seems to me the best way to industrialize an area is to send properly trained individuals into the industrial area, where they can develop techniques and know-how, and eventually they will return and build up that part of the country. I might state that many of our people do go back.

Our approach to the colleges is just this. After all, our headquarters may be in Pittsburgh but we are in every state, we are a local organization in almost every state, and many of our people return upon completion of their training.

Chairman Manning: Here is one for Mr. Johnson: I have heard comments on the loss of initiative on the part of young engineers in the oil industry because of the time lag between suggestion of ideas and their acceptance. Do you meet this problem in your company?

A. J. Johnson: I suppose in any large organization there are individuals who have ideas that do not get tried immediately. But I believe I can in all sincerity say that in our organization, the framework and structure of the teamwork which we have developed are such that we do recognize pretty well every idea that is worth while. If it isn't worth while our senior staff is certainly anxious to explain to younger men why those ideas cannot be tried.

Now the oil industry of course has spent a lot of money in the past few years putting in new processes. But I don't think—and I believe I can speak for the industry at large—that any one of us would be likely to turn down any worth-while idea today. I think that goes for any industry, for that matter. I don't think the oil industry lags in its development of ideas.

Chairman Manning: Mr. Lange, are your engineers while in the training period under the jurisdiction of your union? If so, how can you hold them in layoff under seniority rules?

A. J. Lange: We have been criticized because of the fact that the technical man, when he begins his work in our plant, must obtain a union permit in order to work on the actual operation.

Should there be a layoff, the union agreement is such that he is not included. However, if there ever should arise such an occasion, where production is curtailed other jobs which do not fall under union jurisdiction are available so that he could be placed in them and still continue his training.

Chairman Manning: Mr. McKeon, if you were helping a graduate student in selecting his courses, would you advise him to weight his program with courses involving theory and problems such as advanced unit operation, thermodynamics, physical chemistry; or weight his program with more practical subjects, such as ceramics and metallurgy?

J. C. McKeon: That's sort of a toughie, because it's a question of definition again. We recommend that the man weight his program heavily on the fundamental side. Many programs of definitely technological content can be picked up on the job. My recommendation is that a graduate program leading to a Master's degree, should be heavily fundamental.

Chairman Manning: Mr. McEachron, would you give an indication of what a training program involves, and how many staff members you have in such a training program?

K. B. McEachron, Jr.: In the chemical engineering section we have five men, and the men in that section are 80. So you see in that we have one man for every 16 in training. However, as I mentioned, those men themselves are in training at various levels. So there is no permanent staff. The only permanent staff is myself. There are no permanent physicists, chemists, and so on in the program, they all have as much as six or seven years' service with the company.

The first question is difficult to answer because of the value in dollars of the work the man does on his temporary assignments of three months each. We have so well sold the program to the company that the units where those men are assigned take the full salary plus a very low overhead. But essentially, they take the full salary for the three months. Then the man goes on to another section. So if you assume that that is roughly their value—and that may be an exaggerated assumption—you could take the next step and say that is their value on the job, and therefore it doesn't constitute a training cost. Then on the balance of the training program, employing some five men out of 80 is a measure of the cost of the program.

It is not inexpensive. I want to emphasize that. It is comparable with the Ph.D. training, pot in cost to the student but the total cost of Ph.D. training for a three-year program. For a one-year program it is comparable to the total cost again of the Master's degree.

All I can say in justification of the cost so far as the company is concerned, it is considered more than worth it. We have more demands for the men than we can possibly satisfy. And when the division takes a man we charge it for the cost of his training, because that is where the training is going to pay off, in the division to which he goes.

Chairman Manning: Do any of the other members of the panel wish to discuss that question?

A. J. Lange: Insofar as the cost is concerned, there are no limitations whatsoever put on the moneys desired for the educational program within the plant, as well as the educational program outside the plant. The budget, which is merely used as a guide, for education runs at $1200 per month. However, that is exceeded often and no one minds a bit; as a matter of fact, the higher it goes the better it is.

Member: Since the company knows which men take advantage or don't take advantage of the cultural phases, is there any discredit to the men who do not; are they penalized because they don't take the cultural program?

A. J. Lange: They certainly are not.

Chairman Manning: I have a $64 question for you, Karl. Twenty-five hours a week on problems outside of regular duties scarcely allow young engineers much time for extracurricular activities. Doesn't this keeping his nose to the grindstone make the young engi-

neer dissatisfied, and isn't it a hindrance to his home life?

K. B. McEachron, Jr.: Perhaps I can testify personally. I took the advanced program myself three years, and I was married at the time. I will have to admit that the development of this program—particularly the earlier program, happened to be originated for us by Dr. Doherty of Carnegie some 25 years ago, at a time when on the average the man was 22 years old, not married, and had no family. We expect we will return to that condition in the future. We have had to make concessions because of that factor in the program.

But the test of it is the usefulness, and the young men who come to us elect to take the course. Accompanied with the selection is some "hazing" in emphasizing, time and time again, how much time it is going to take. The place of those graduates from previous years in the company's operations today is what sells the idea.

We have included in the program, in the last five years, what we call human relations, about 16 hr. out of the total time they are released from some of the technical problems in order to experiment, if you will, in some of the human relations fields. I would like right here, if I might, to comment on one other question asked, and that was, should you concentrate on fundamentals in the undergraduate curricula particularly, or on the social-humanistic stem, what should be the division? I think the important thing in both areas, of course, as Dr. Jones has said, is to develop an interest in the young man's continuing his education, formally or informally. I think that is particularly important in the social-humanistic area, as opposed to transmitting factual information. The young man in college has little experience with either industry or life as he has to live it afterwards. If you try to tell him something about life out of the textbooks, it is difficult to get it across. It is much easier to tell him something about the theory of engineering or processes than about life.

So we emphasize the humanistic and human relations end of it even in the first year of this technical program, in the sense that it is important. If we get across the idea that it is important, they will go on and develop themselves, we don't have to worry.

Chairman Manning: Mr. Lange, in a training program such as you outlined, the goal is to be the very high positions. Since only a small number achieve this goal, because of normal turnover, plus those who fall by the wayside, how do you use those men who fall by the wayside but remain with the company after the training?

A. J. Lange: That is difficult. If the individual on the in-plant-training program cannot apply himself as the company desires, he is informed of that fact. He is informed also that unless he does improve himself to the extent that is expected of him he will have to be eliminated from the plant experience program, because he in turn would be holding back someone else in a particular job category which would be a part of the training experience. There are some jobs in the organization which do not require a lot of thought on the individual's part, but they are quite far afield if he is a chemical engineer. That is in moving him to another job, he is not released. He is placed in another job where he would to a certain extent stagnate. That attitude, however, is taken only in case of extreme necessity. Usually the individual has sufficient gumption that he starts looking around to see where he could apply himself in another organization.

Insofar as the matter of moving up in the organization there are—I should say there were, in prewar days, a tremendous number of people who left Seagram's for excellent and of course better jobs. Many of the people who had gone through the training programs in former years left for much better jobs and where competition was not as great. Now however the economic conditions are different. Most of the men have families and have become localized and stabilized in their communities. Having had to buy homes and so forth, they have slowed down that turnover terrifically, which of course does slow down the progress of the individual toward the top.

However, I would like to say that the individual who is on the ball, so to speak, will move on up that ladder and a place will by all means be made for him. No one is held back if he has the ability.

Member: I would like to ask one question about training for management. I think most of the panel members, except for discussion of philosophy, have devoted themselves mainly to the training of engineers for technical profession on the individual level.

I wonder if we should comment further on training engineers to broaden themselves so they can take on responsibilities in other professions?

K. B. McEachron, Jr.: We have had that problem facing us particularly in the last five or six years, because as most of you probably know, we have gone to a much higher degree of decentralization than in former years. So we have some eight or nine independent businesses, and even independent companies, almost, within those businesses. That has called upon us to develop men with more than engineering ability, or more than manufacturing ability, more than sales ability. To develop those men we have depended on a program which is not much different from those of several other companies (New York Edison is one that I am familiar with), where we take men and move them from assignments in engineering, or in manufacturing, or in sales, or in some cases in accounting, into the other areas of the total business picture. We don't do that in a formal way. By that I mean we don't make this a formal program and put somebody on it in that sense. In fact, what we do is tell the young man that we have asked him to move to this section, we think it would be good experience, if he is an engineer, to get some experience in manufacturing, we would like him to spend a year or two in this particular spot. With no promises as to where he is going after that, and no promise of further training or anything else, it is on an individual basis of that kind.

Usually we don't make those selections until a man has demonstrated proficiency in a supervisory function, if he is an engineer in an engineering function, let's say. We are interested in training management people. But always we avoid the label of people who are slated, let's say, for management positions and no one else having a crack at it.

J. C. McKeon: I won't add much on this, but I want to emphasize avoiding the prelabeling, because the man expects a manager's job right away. If your screening is not good you can get in trouble.

We make every effort to spot supervisory talent and provide a careful rotation program. You see, in the industrial field, to make good as an engineer you have to be a specialist. But to become top management you must be a generalist. About the only way you can make a generalist out of a specialist is to have him work in different fields, give him responsibility in various activities, so when he moves to top management he doesn't still think of himself as a process engineer, for example, or a design engineer.

Then on the lower levels we do have courses where they sit down and discuss supervisory problems. That is on the lower level than top management. That is important. Those subjects include economics, they include applied psychology, although we don't use those words. We have many such programs going on to develop our people.

I like to look at it this way. There are many facets of this whole management development. Some of them can be accomplished by in-company training programs. In others we need the cooperation of the colleges.

(The End)

BATCH AZEOTROPIC DISTILLATION

Effect Of Charge Composition On Recovery

LLOYD BERG, H. C. CARPENTER, and J. B. DALY

Montana State College, Bozeman, Montana

Batch separation by azeotropic distillation of five different systems was investigated to determine the effect of charge composition on the recovery of the constituents. Separations investigated were methylcyclohexane from toluene using 1-propanol as the entrainer, methylcyclohexane from toluene using 2-butanone, cyclohexane from benzene using acetone, n-octane from ethylbenzene using acetic acid, and ethylene dichloride from dioxane using 1-propanol.

IN the separation of two compounds by straight rectification, it is axiomatic that the greater the proportion of either of the constituents in the mixture, the greater will be the recovery of that constituent. Thus, with a given rectification column, a mixture of benzene and toluene containing 90% benzene will yield a greater proportion of a given purity of the benzene present in the charge than will a mixture of these two compounds containing only 40% benzene. The same holds true for the less volatile constituent, toluene.

In the field of azeotropic distillation, no data exist in the literature concerning this point, but it has been generally taken for granted that the same generalization held. It was the purpose of this work to determine the effect of the charge composition when separation is effected azeotropically in batch columns. The work was designed to indicate whether or not this generalization might be applied to both the more and the less volatile component when the separation was made by azeotropic distillation.

Separation of methylcyclohexane from toluene using 1-propanol as the entrainer was selected for detailed study. Methylcyclohexane can be separated from toluene by straight rectification but with considerable difficulty, that is a column composed of a large number of theoretical plates is required. The ease of separation of this mixture is appreciably enhanced by the use of azeotropic distillation and 1-propanol is one of a number of entrainers which can be used to advantage. Eight different charge compositions, exclusive of entrainer, were investigated ranging in 10% increments from 20% methylcyclohexane—80% toluene, to 90% methylcyclohexane—10% toluene. Each of these mixtures was investigated at four different reflux ratios: 5 to 1, 10 to 1, 20 to 1, and 30 to 1. Since results obtained were not wholly as expected, it was decided to investigate somewhat more briefly a variety of azeotropic systems in order to preclude the possibility of the conclusions applying only to one particular case. Four more systems were selected for investigation which represented a variety of hydrogen-bonded liquids (*3*). A system not separable by straight rectification was included. Three compositions, namely 20%, 40%, and 60% of the more volatile constituent, were investigated for each system but at only one reflux ratio, 20 to 1. Systems investigated were methylcyclohexane-toluene using 2-butanone as the entrainer; cyclohexane-benzene with acetone; *n*-octane-ethylbenzene with acetic acid; and ethylene dichloride-dioxane with 1-propanol. The cyclohexane-benzene system was selected because a constant boiling mixture exists between these two and it therefore represents a system which cannot be separated by straight rectification. The ethylene dichloride-dioxane-1-propanol system is of interest because it represents a combination where all three liquids are capable of forming hydrogen bonds. Hydrocarbons, which constitute part of all the other systems studied do not have any hydrogen-bond-forming ability.

Because no data were available in the literature concerning the actual per cent recovery possible with a standardized column by straight rectification for the systems studied, it was necessary to carry out some nonazeotropic runs to provide data for comparison purposes.

The observed boiling temperatures of compounds and fractions listed in this paper were not corrected to standard pressure. The average barometer reading at the laboratory where this work was performed is 635 mm. Hg.

Equipment, Methods and Compounds

Equipment. The following equipment was used in this investigation: a precision rectification column, a Corad constant reflux ratio condenser, a graduated water-cooled receiver, a Harvard-type triple-beam balance, a mercury-filled *U*-type manometer, round bottom glass distilling flasks with side arms, a Valentine refractometer, a ceramic heater, Powerstats, glass stem mercury thermometers, and several 250-ml. separatory funnels.

The column was constructed of three lengths of glass tubing arranged concentrically and held in this position by strips of asbestos tape and glue. The inner tube, 33 mm. I.D., was packed with ⅛-in., stainless steel, Fenske packing. A thermometer was fastened to the outside of this tube near the center. The middle tube was wound with Nichrome wire to provide heat for the column. The amount of heat supplied was controlled by means of a Powerstat. The outside tube provided additional insulation and also protection for the Nichrome winding. The over-all height of the column was 48 in. The height of the packing was 46½ in.

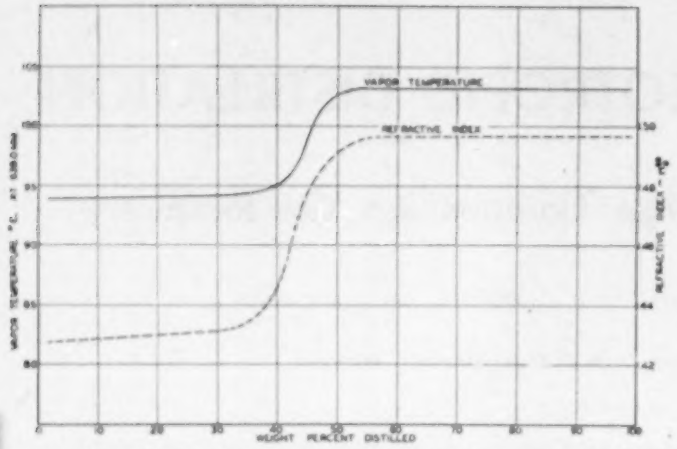

Fig. 1. Azeotropic Rectification of Toluene-Methylcyclohexane Mixture Using 1-Propanol as Entrainer.

The Corad head was attached to the top of the column by a 29/42 standard tapered ground glass joint. The head was adjusted to give the desired reflux ratio. A second thermometer was inserted in the head to measure vapor temperature.

The distilling flasks used were 1- and 2-l. round bottom flasks with 35/25 ground glass ball joints on the necks to fit the bottom of the column. Each flask also had a side arm ending in an 18/9 ball joint to fit the manometer.

The manometer was constructed of glass tubing bent in a *U* shape. One end of the tube was left open to the atmosphere and the other connected to the side arm on the distilling flask. The manometer was approximately 12 in. high and was about half filled with mercury.

The heater used consisted of Nichrome coils mounted on a ceramic base. By means of a second Powerstat the flow of heat was controlled.

The Valentine refractometer was of the glass-prism type. The refractive indices were read at $20 \pm 0.1°$ C., with the exception of the readings taken on mixtures of acetic acid and *n*-octane which were read at $30 \pm 0.1°$ C.

The Powerstats were small autotransformers manufactured by Superior Electric Co. The maximum input was 7½ amp. at 110 v. The output ranged from 0 to 135 v.

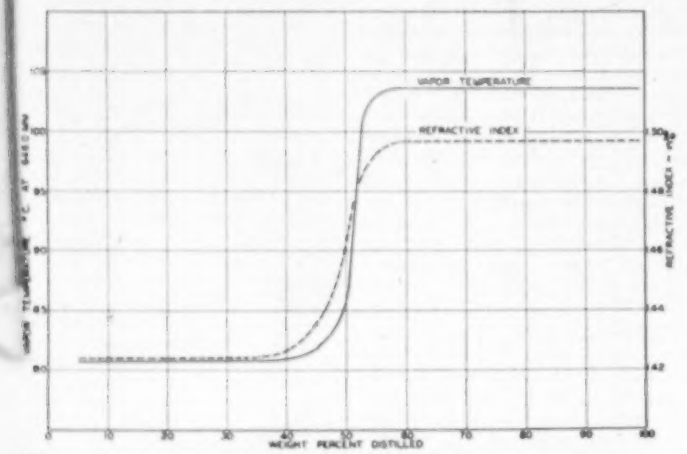

Fig. 2. Non-Azeotropic Rectification of Toluene-Methylcyclohexane Mixture.

TABLE 1.—AZEOTROPIC DATA

Component	Entrainer	Azeotrope Boiling Point °C. Reference (5)	Azeotrope Boiling Point °C. Observed	Azeotrope Pressure, mm. Observed	Azeotrope Weight Per Cent Entrainer Reference (5)	Azeotrope Weight Per Cent Entrainer Observed
Methylcyclohexane	1-Propanol	86.0	80.6	638	41.5	34.3
Methylcyclohexane	2-Butanone	78.0	72.4	639.8	70	74.4
Cyclohexane	Acetone	< 54.0	48.3	639.4	< 85	66.6
n-Octane	Acetic Acid	105.5	99.4	639.7	82.5	55.0
Ethylene Dichloride	1-Propanol	80.65	74.8	633.7	19.0	16.0

Methods

1. *Determination of Azeotropic Compositions.* Composition of each azeotrope was obtained from the literature (*5*). A charge of this composition was prepared and distilled. Samples of the distillate were taken until the refractive index became constant. Composition of the azeotrope was obtained from a plot of refractive index versus composition. This plot was made by determining the refractive index of several samples of known composition. In order to check the experimental value, a new charge was prepared using the experimental value of the azeotropic composition. This charge was distilled and samples of the distillate were taken until the refractive index became constant. In all cases this composition agreed with the original experimental value of the azeotropic composition. In order to use this method on the acetic acid—*n*-octane azeotrope, it was necessary to determine the refractive index at 30° C. At 20° C. the samples were two phase and could not be analyzed by refractive index. However, at 30° C. the samples were all single phase. Azeotropic data are given in Table 1.

2. *Preparation of Charges for Azeotropic Runs.* Charges were made up on a weight basis. Due to operational holdup of the column it was found necessary to make up the charge so that there was at least 120 g. of the less volatile component. The smallest charge used was 300 g. of components exclusive of entrainer in all cases except those runs containing only 10 per cent toluene. The amount of entrainer added was dependent upon the amount of azeotrope former present in the original mixture. In all cases a two-gram excess of entrainer was added to insure complete removal.

For a charge of 10 per cent toluene and 90 per cent methylcyclohexane, the size of the charge, 120 g. of toluene and 1080 g. of methylcyclohexane plus the necessary amount of entrainer, became too large for the still pots available. Since 120 g. of toluene represented the minimum amount necessary to take care of column holdup and drive off completely the azeotrope, a chaser was introduced. Use of a chaser permitted cutting the charge to a size suitable for proper handling. Cumene was the chaser employed because it forms no azeotrope with toluene, methylcyclohexane, or 1-propanol and the break in the distillation curve between cumene and toluene is sharp. The size of the charge, using a chaser, could be cut to 50 g. of toluene, 450 g. of methylcyclohexane, 150 g. of cumene plus the required amount of entrainer.

3. *Azeotropic Runs.* After drying the column by passing compressed air through it, the charge was placed in the distilling flask and the flask attached to the column. The manometer was attached to the side arm of the distilling flask. The heater and the Nichrome winding on the column were attached to the Powerstats and the power turned on. To insure complete wetting of the packing the column was allowed to flood. After flooding, the Powerstat connected to the heater was adjusted until the pressure drop across the packing was 15 ± 1 mm. Hg. This pressure drop was equal to approximately 80 per cent of the pressure drop at the flooding point and was so maintained for all of the runs. The Powerstat connected to the column winding was adjusted until the thermometer on the column showed a temperature approximately 10° C. above that of the overhead vapor. The column was then allowed to run at total reflux until the vapor temperature became constant, usually about one hour.

The initial vapor temperature was noted and the distillate was allowed to pass into the cold receiver. The temperature was recorded every 5 ml. until the boiling point of the azeotropic mixture at the atmospheric pressure of this laboratory (about 635 mm.) was reached; at this time the first sample was taken. Comparatively large samples were taken until all the azeotropic mixture was removed. During the transition from azeotrope to less volatile component, the samples were reduced in order that the distillation curve might be defined more accurately. Larger samples were again taken after the transition until the charge was nearly exhausted from the distilling flask.

Each sample was weighed and the refractive index determined. Next, the samples were placed in separatory funnels and washed with distilled water until all of the entrainer was removed. They were then placed over calcium chloride and allowed to dry. After drying, the refractive index of each sample was determined again and this value was used in Figures 1 and 2.

The column was allowed to drain back into the distilling flask and, after cooling, the flask was removed. The bottoms were weighed and the refractive index of the bottoms determined. The static holdup was found to be about 5 g.

Data tabulated in Tables 2 and 3 were plotted as weight per cent distilled versus vapor temperature and also as weight per cent distilled versus midpoints of the refractive index steps. Figure 1 (Azeotropic Rectification of Toluene-Methylcyclohexane Mixture Using 1-Propanol As Entrainer) is an example for an azeotropic run. It is taken from Run 11,

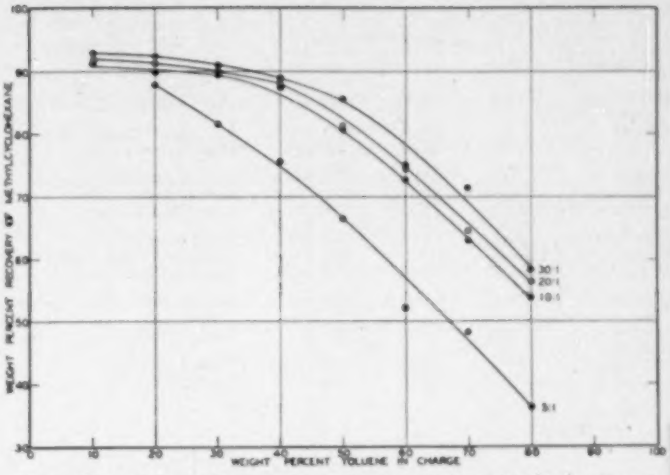

Fig. 3. Effect of Charge Composition of Recovery of More Volatile Component in Toluene-Methylcyclohexane-1-Propanol System.

TABLE 2.—RESULTS FROM SYSTEM TOLUENE-METHYLCYCLOHEXANE-1-PROPANOL

Charge Compositions, Reflux Ratios and Recoveries for Azeotropic Runs n-Propyl Alcohol as Entrainer

Run No.	Charge Composition Weight Per Cent Toluene	Methylcyclohexane	Reflux Ratio	Weight Per Cent Recovery 98 Wt. % Methylcyclohexane	99.5 Wt. % Toluene
1	80	20	5:1	36.5	71.5
2	80	20	10:1	54.2	82.5
3	80	20	20:1	56.5	86.2
4	80	20	30:1	58.5	90.9
5	70	30	5:1	48.5	70.6
6	70	30	10:1	63.2	81.6
7	70	30	20:1	64.6	88.3
8	70	30	30:1	71.5	91.4
9	60	40	5:1	52.3	72.4
10	60	40	10:1	72.9	82.1
11	60	40	20:1	74.5	88.5
12	60	40	30:1	75.0	93.2
13	50	50	5:1	66.5	69.6
14	50	50	10:1	80.6	82.5
15	50	50	20:1	81.4	86.8
16	50	50	30:1	85.7	92.3
17	40	60	5:1	75.8	72.5
18	40	60	10:1	87.5	86.5
19	40	60	20:1	88.1	87.4
20	40	60	30:1	89.0	89.8
21	30	70	5:1	81.6	73.6
22	30	70	10:1	89.5	84.5
23	30	70	20:1	90.0	86.6
24	30	70	30:1	91.0	89.0
25	20	80	5:1	89.0	75.6
26	20	80	10:1	90.0	84.4
27	20	80	20:1	91.4	87.3
28	20	80	30:1	92.5	91.5
29	10	90	5:1	....	....
30	10	90	10:1	91.2	82.0
31	10	90	20:1	92.0	87.0
32	10	90	30:1	93.0	90.0

TABLE A.

Compound	Grade	Refractive Index Observed	Refractive Index Literature	Source
Methylcyclohexane	Tech.	1.4235	1.4230 (2)	Dow Chemical Co.
Toluene	C.P.	1.4965	1.4968 (2)	J. T. Baker Chemical Co.
2-Butanone	Tech.	1.3787	1.3807* (4)	Shell Chemical Corp.
Benzene	Tech.	1.5010	1.5012 (2)	General Chemical Co.
Cyclohexane	Tech.	1.4262	1.4262 (2)	Shell Chemical Corp.
Acetone	99.5%	1.3588	1.3588† (4)	B. R. Elk & Co., Inc.
Ethyl-benzene	Tech.	1.4958	1.4958 (2)	Dow Chemical Co.
n-Octane	Tech.	1.3979	1.3976 (2)	Connecticut Hard Rubber Co.
Acetic Acid	99.5%	1.3683	1.3718 (4)	Merck & Company, Inc.
Dioxane	Tech.	1.4224	1.4232 (4)	Carbide and Carbon Chemicals Corp.
Ethylene Dichloride	Tech.	1.4449	1.4443 (4)	Dow Chemical Co.
1-Propanol	C.P.	1.3859	1.3854 (4)	Eimer and Amend
Cumene	C.P.	1.4916	1.4912 (2)	Dow Chemical Co.

* Observed at 15.9° C.
† Observed at 19.4° C.

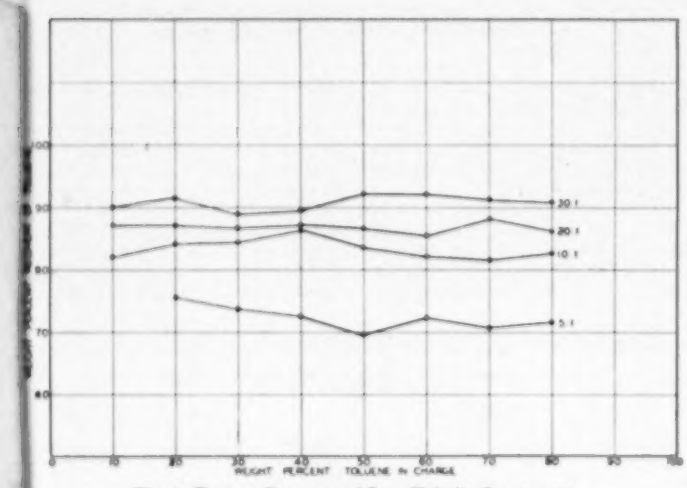

Fig. 4. Data on Recovery of Less Volatile Component.

TABLE 3.—RESULTS FROM SEVERAL AZEOTROPIC SYSTEMS

Run No.	Charge Composition Weight Per Cent		Entrainer	Weight Per Cent Recovery 99.5 Wt. % Purity	
	Toluene	Methylcyclohexane	2 Butanone	Toluene	Methylcyclohexane
1	80	20		92.3	92.9
2	60	40		92.3	96.4
3	40	60		92.0	96.4
	Benzene	Cyclohexane	Acetone	Benzene	Cyclohexane
4	80	20		89.5	86.2
5	60	40		89.3	94.4
6	40	60		88.1	94.6
	Ethyl-benzene	n-Octane	Acetic Acid	Ethyl-benzene	n-Octane
7	80	20		89.5	65.7
8	60	40		89.6	89.4
9	40	60		89.2	91.4
	Dioxane	Ethylene Dichloride	1 Propanol	Dioxane	Ethylene Dichloride
10	80	20		88.1	48.2
11	60	40		88.3	76.5
12	40	60		88.1	79.3

Table 2, and contained a charge consisting of 60 wt. % toluene, 40 wt. % methylcyclohexane, 1-propanol as entrainer and was run at a reflux ratio of 20:1. Per cent recoveries were determined from these plots.

4. *Nonazeotropic Runs.* Charges for the nonazeotropic runs were made in exactly the same manner as for azeotropic runs with the exception that the entrainer was omitted. The same column was used with the same reagents under similar conditions. They were carried out at only one reflux ratio, 20:1. A chaser, cumene, was used for the runs containing 10% toluene, 90% methylcyclohexane and 20% toluene, 80% methylcyclohexane. These data are tabulated in Table 4.

The same type of plots was made for the nonazeotropic runs as for the azeotropic runs. Figure 2 (Nonazeotropic Rectification of Toluene-Methylcyclohexane mixture) is an example of a nonazeotropic run of 60 wt. % toluene, 40 wt. % methylcyclohexane at a reflux ratio of 20:1, and is taken from Run 3, Table 4.

Compounds. All the reagents used in this investigation were purified by fractionation. Only the fraction having a boiling range of ±0.2° C. was used.

See Table A.

Sample Calculations

These calculations are all based upon Run No. 11, Table 2—60 wt. % toluene, 40 wt. % methylcyclohexane.

a. To determine amount of entrainer to add to charge:
Azeotrope composition = 65.7 wt. % methylcyclohexane, 34.3 wt. % 1-propanol. Total weight of hydrocarbon charge = 300 g.
Weight toluene = (.60) (300) = 180 g.
Weight methylcyclohexane = (.40) (300) = 120 g.

$$\text{Weight 1-propanol} = (120)\frac{(34.3)}{(65.7)}$$

plus 2 g. = 64.6 g.

b. To determine weight per cent recovery of methylcyclohexane:
From Figure 1 weight per cent distilled at refractive index of 1.42500 (98 wt. % methylcyclohexane) on refractive index curve = 37.3
Refractive index curve exceeds 1.42500 beyond 37.3 wt. % distilled.
Weight per cent methylcyclohexane recovered

$$= \frac{(0.373)(364.6)(65.7)}{120} = 74.5$$

c. To determine weight per cent recovery of toluene:
From Figure 2 weight per cent distilled at refractive index of 1.49600 (99.5 wt. % toluene) on refractive index curve = 57.8
Refractive index curve exceed 1.49600 beyond 57.8 wt. % distilled.
Weight per cent toluene recovered

$$= \frac{(1.00 - 0.578)(364.6)}{180} \times 100 = 85.5$$

Results

The generally accepted concept that in the separation of a binary mixture by straight rectification, the greater the proportion of either component in the charge, the greater will be its recovery is borne out by the data listed in Table 4 for nonazeotropic separations. In each of the three cases listed, the recovery of both the more or the less volatile component increases as its proportion in the charge is increased.

In azeotropic distillation, the results obtained do not follow this generality. The more volatile component shows a similar relationship between recovery and its proportion in the charge but the recovery of the less volatile component appears to be independent of charge composition. Data from Table 2 have been plotted to yield Figures 3 and 4. Figure 3 shows the effect of charge composition on the recovery of the more volatile component in the system toluene-methylcyclohexane-1-propanol. Recovery of the more volatile component, methylcyclohexane, decreases as its proportion in the charge is decreased. The effect of reflux ratio is merely to reduce recovery as the reflux ratio is reduced. While the purity of the methylcyclohexane is higher and the recovery substantially greater in the azeotropic runs than in the nonazeotropic, the effect of both charge composition and reflux ratio is exactly the same as would be obtained in nonazeotropic distillation.

Figure 4 presents the data, also taken from Table 2, on the recovery of the less volatile component for this system. Here the recovery of the toluene is virtually independent of its quantity in the charge. The higher the reflux ratio, the greater the recovery obtained as might be expected from analogy with nonazeotropic distillations. The constant recovery of toluene, regardless of its proportion in the charge, is contrary to any experience obtained with nonazeotropic separations and must be considered as a unique characteristic of this azeotropic separation. The increase in recovery by azeotropic distillation is very marked in this case. Figure 5 presents a graphical comparison of azeotropic and nonazeotropic separation of this system.

When the charge contained less than 50 wt. % toluene, the recovery of toluene by azeotropic distillation, even at 5:1 reflux ratio, is greater than at 20:1 in nonazeotropic distillation. At reflux ratios of 10:1, 20:1, and 30:1 recovery in the azeotropic runs is substantially higher at all percentages of toluene charged. This is a feature of this entrainer in this particular system only, for it has been shown that azeotropic distillation does not always give an improvement over straight rectification (*1*).

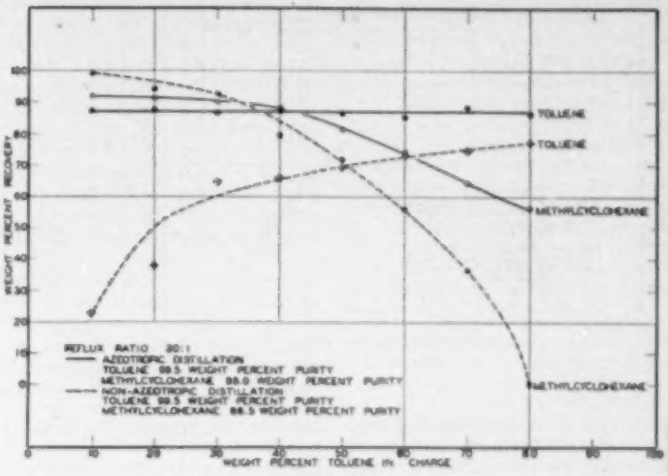

Fig. 5.

To expand further the study and to determine whether or not the phenomenon noted for the system toluene-methylcyclohexane-1-propanol was generally applicable to all azeotropic separations, several systems representing a wide variety of compounds were investigated. This could be accomplished with considerably less data on each system and therefore only three compositions and one reflux ratio 20:1 were investigated for each system.

The next system studied involved only a change in entrainer, substituting 2-butanone, a ketone, for the alcohol 1-propanol. Results of the same nature were obtained and are listed as Runs 1-3 in Table 3. When separated by azeotropic distillation in a batch column, the weight per cent recovery of the toluene, the less volatile component, is independent of the per cent toluene in the charge. Recovery of the methylcyclohexane, the more volatile component, increased as the per cent of methylcyclohexane in the charge was increased. A comparison of the separation of this system, both azeotropically and nonazeotropically is given in Figure 6.

The next system chosen, namely benzene-cyclohexane with acetone as the entrainer was selected because benzene and cyclohexane form a binary azeotrope with each other and cannot, therefore, be separated from each other by straight rectification. For this reason, no data on this pair are given in Table 4. Runs 4-6 in Table 3 show that the purity of

TABLE 4.—CHARGE COMPOSITIONS AND RECOVERIES FOR NON-AZEOTROPIC RUNS

Run No.	Charge Composition Weight Per Cent		Weight Per Cent Recovery		
			Toluene	Methylcyclohexane	
	Toluene	Methylcyclohexane	99 Wt. % Purity	99 Wt. % Purity	98.5 Wt. % Purity
1	80	20	77.5	0	0
2	70	30	75.0	0	36.7
3	60	40	73.4	0	56.4
4	50	50	70.0	0	72.0
5	40	60	66.3	0	79.2
6	30	70	65.0	0	92.8
7	20	80	38.0	0	94.3
8	10	90	23.0	0	99.0
	Benzene	Cyclohexane	Benzene-Cyclohexane separation impossible, azeotrope forms between these two.		
	Ethylbenzene	n-Octane	Ethylbenzene	n-Octane	
9	80	20	78.5	0	73.1
10	60	40	75.0	0	87.5
11	40	60	73.7	0	95.9
	Dioxane	Ethylene Dichloride	Dioxane	Ethylene Dichloride	
12	80	20	65.3	0	Not Determined
13	60	40	64.1	50.9	
14	40	60	63.6	60.8	

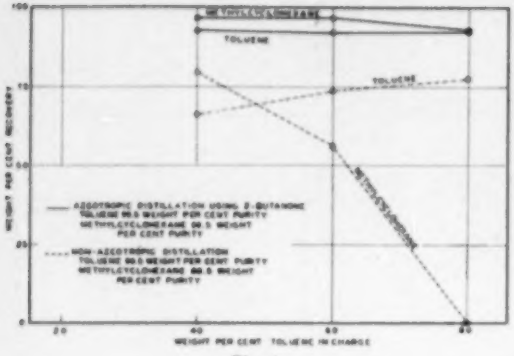

Fig. 6.

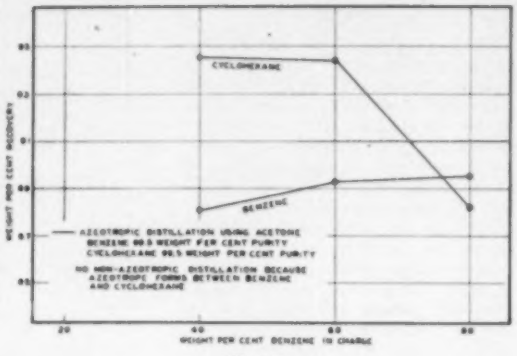
CYCLOHEXANE
BENZENE
AZEOTROPIC DISTILLATION USING ACETONE
NO NON-AZEOTROPIC DISTILLATION BECAUSE AZEOTROPE FORMS BETWEEN BENZENE AND CYCLOHEXANE
WEIGHT PER CENT BENZENE IN CHARGE

Fig. 7.

the recovered product exceeds 99.5 wt.% and that the weight per cent recovery of benzene, the less volatile component, is independent of the per cent of benzene in the original charge, while the recovery of cyclohexane, the more volatile component, is dependent on its proportion in the charge. Figure 7 shows only the azeotropic recoveries since nonazeotropic separation is not possible.

Acetic acid was the entrainer employed in the separation of *n*-octane from ethylbenzene. Runs 7-9 in Table 3 show that the purity of the recovered products and the recoveries when separated by azeotropic distillation are in accord with the rest of the study. Results of the nonazeotropic separations are shown as Runs 9-11 in Table 4 and correspond with those obtained for methylcyclohexane-toluene. A comparison of azeotropic and nonazeotropic separations for the system *n*-octane-ethylbenzene is shown in Figure 8.

A nonhydrocarbon system, dioxane-ethylene dichloride with 1-propanol as the entrainer gave results that were similar to the other systems reported. Table 4 shows that the purity of the ethylene dichloride recovered exceeded 99.5 wt.%.

The fact that the purity of ethylene dichloride obtained by nonazeotropic distillation was approximately the same as that obtained by azeotropic distillation indicates that purity is not always enhanced by azeotropic distillation. Figure 9 presents a comparison between the azeotropic and nonazeotropic distillations for the system dioxane-ethylene dichloride.

Conclusions

The following conclusions may be drawn:

1. Recovery of the less volatile component in the charge is independent of its per cent in the charge when the separation is made by azeotropic distillation.
2. Quantity at a given purity of the less volatile component is increased by azeotropic distillation.
3. Recovery of the more volatile component in the charge is dependent on its per cent in the charge for both azeotropic and nonazeotropic distillation.
4. Purity of the more volatile component in the charge is not always increased by azeotropic distillation but the quantity at a given purity recovered is increased.

Acknowledgment

The authors acknowledge with thanks the courtesy of the Dow Chemical Co. which furnished the methylcyclohexane, ethylbenzene, and ethylene dichloride; of the Shell Chemical Corp. which supplied the 2-butanone and cyclohexane; and the Celanese Chemical Co. which donated 1-propanol.

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Discussion

H. D. Evans (Shell Development Co., San Francisco, Calif.): The au-

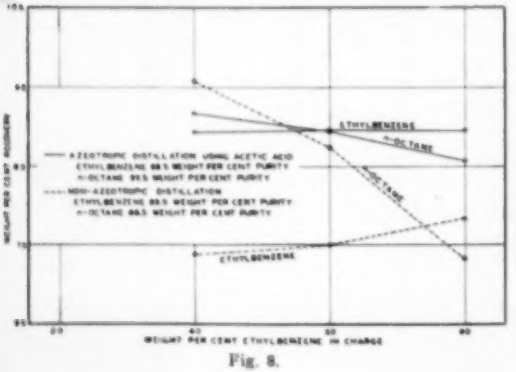

Fig. 8.

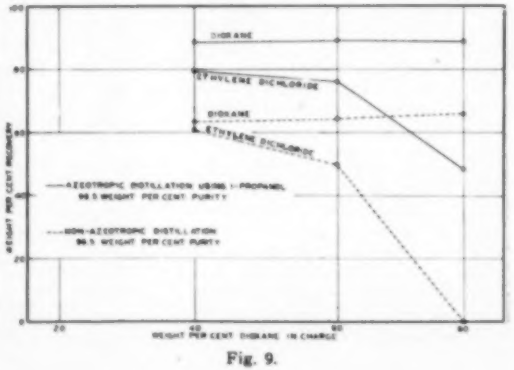

Fig. 9.

thors' experiments have demonstrated the advantages of batch azeotropic distillation over nonazeotropic batch distillation for a number of different systems. I note the authors' initiative in verifying their original results for the system methylcyclohexane, toluene, and 1-propanol by experiments on a number of other systems.

The effect of constant recovery of the less volatile components, independent of its percentage in the charge is an interesting one. It is believed that the reason for this constant recovery should be looked for in the interrelation of activities and concentrations of the system. Until such a time as experimental results are verified, by a study of these activities, it is believed that it may be unwise to extrapolate these conclusions to other types of systems.

From a study of the paper, I gather that the authors used a constant composition for this azeotropic binary system, independent of the concentration of the third component in the system. For instance, in the methylcyclohexane, toluene, 1-propanol system, I believe they used the concentration of the binary azeotrope, methylcyclohexane and 1-propanol, in calculating their percentage recovery on various toluene concentrations added. Since the activities of both methylcyclohexane and propanol may be affected differently by the presence of varying amounts of toluene, it is possible that the concentration of methylcyclohexane and 1-propanol in the ternary distillation might be different from the binary system concentration. This would affect the calculated recovery.

Has any attempt been made to study the activities of these systems, and to verify your experimental conclusions on that basis? Also, were any experimental measurements taken of the actual ratios of methylcyclohexane to 1-propanol during the actual distillation runs?

Lloyd Berg: The answer to your first question is no. The data were not calculated in terms of activity coefficients. Experimental data were worked up and plotted as we have shown on the Figures.

For the second question; the composition of the azeotrope—consider the methylcyclohexane, 1-propanol azeotrope used in the first example. The composition is available in the literature at atmospheric pressure. It is well known that the composition of azeotropes differs somewhat at different pressures. Since we were working at a pressure considerably different from atmospheric, 635 mm. we had to determine the composition of the azeotrope at that pressure. In every case that has been done by making up mixtures. We are making up several mixtures, one which was richer in methylcyclohexane than the literature value, and one which was leaner than the literature value. These mixtures are put in a precision column and rectified and the composition of the overhead determined. Then we plot the change of the overhead composition with regard to the bottoms versus the composition of the charge, and connecting the points—provided of course that one changes one way and one changes the other—where the line passes through zero deviation, we believe that to be the true azeotrope composition. We then made up that charge and put it in the column, and in every case, it turned out that we obtained the same overhead composition as bottoms. In that way, we established the composition of the azeotrope before we went ahead and made up our charge compositions for these runs.

In the distillation, the first overhead is the azeotrope, and we determined in every case that what we were getting in the first part of the runs was this azeotropic composition which we had previously determined. We never noticed that the effect of toluene would be to change the azeotrope composition. That is, we would never get a different azeotrope composition when we rectified from a mixture containing it and toluene than when we rectified it alone.

J. S. Walton (Oregon State College, Corvallis, Ore.): I'm sure that my seniors would be helped, and I'm not sure some of the rest of us would not be helped, if the authors and authorities in these fields would be a little more specific and exact in defining what is meant by azeotropic distillation, extractive distillation, distillation of azeotropes, etc. Some authorities choose to consider all these operations as being separate. Others treat them as variations of the general behavior of a system, wherein the activity coefficients are changed by the addition of the entrainer. I suggest that future authors be precise in definitions, and I'm sure that it will help the reader in the field of these investigations if all of us know exactly what is meant when the author discusses azeotropic distillation, extractive distillation, etc.

M. J. P. Bogart (Lummus Co., New York, N. Y.): Have you been able to rule out the possibility that the poorer recovery in nonazeotropic distillation is due to the difference in the holdup in the column of the residual amounts of either component going overhead? In the case of azeotropic distillation the entrainer present may help to clear the column of those last few drops of either the heavy or the light component, whichever is being distilled off at the time.

Lloyd Berg: I don't believe the entire difference could be assigned to the effect of holdup because the amount of improvement compared with the amount of the charge is enough so that factor alone could not account for it. The charges in every case amounted to at least 500 mm. The operating holdup of the column is about 100 ml. and the static holdup is about 20 ml. The larger charges are as high as 1500 ml. and the per cent differences between azeotropic and nonazeotropic runs are, I believe, sufficient so that the change couldn't be accounted for solely on the basis of the diluting effect of the entrainer.

Anonymous: Have you taken into consideration the possible effect of the slight amount of excess of azeotropic former that he uses? He uses about 2% excess azeotrope former. We have found in less efficient distillations, that you distill over-all mixtures of azeotropes in your more volatile components, and azeotropic former. Therefore, you're bleeding the azeotropic former before you have removed all your nonaromatic hydrocarbons, and I think this might affect the recovery of not only the more volatile component, but also of the other.

Lloyd Berg: The effect of excess entrainer was something to which we gave a great deal of consideration. In making up the charges, it is obvious that one can't have it exactly correct; that is, that you're going to make some slight error. We had to decide which way to err. At first we thought to make these charges with a constant per cent excess of entrainer, say 2%. The quantity of the charge had to be varied somewhat because when the charge is to contain only 10% of the less volatile constituent and the static holdup is 100 ml., it means that you had to have at least 150 mm. of the less volatile component. If that is only 10% of the charge without the entrainer, it builds up to a big charge. Therefore, if we were to use a constant per cent excess of entrainer, it would be a large amount of entrainer. We decided against that method. The amount of material that had been previously distilled through the column before we reached the break would not make any difference as far as the operation of the column was concerned. We decided we would always use a constant quantity of entrainer rather than a constant per cent of entrainer so that the effect of excess entrainer would be the same in every break; that is, the break from the azeotrope over to the zeotrope. The effect of the excess should be the same because the quantity of the entrainer in excess was always the same.

(Presented at Tenth Regional Meeting, Los Angeles, Calif.)

CONTINUOUS FLOW STIRRED-TANK REACTOR SYSTEMS

I. Design Equations for Homogeneous Liquid Phase Reactions. Experimental Data

JOHN W. ELDRIDGE† and EDGAR L. PIRET

University of Minnesota, Minneapolis, Minnesota

Theoretical equations for the performance of a series of continuous flow reaction vessels having uniform mixing have been extended to higher order unidirectional reactions and to reversible, consecutive and simultaneous reactions. A convenient graphical method has been devised to solve the design equations. Computed curves are presented for the solution of the important case of second-order reactions with unequivalent reactant concentrations.

Experimental data on one to five reactors in series are shown to agree well with the predicted degree of completion.

IT is not necessary to argue the proposition that continuous operations are gaining ever-increasing importance in the chemical process industries. Constant improvements in automatic control techniques and instrumentation are steadily widening the range of application of continuous processing, and ever-rising labor costs are inherently effecting an increasing need for greater productivity per employee. Consequently there is a strong incentive for management to consider "going continuous" wherever technically feasible.

In view of this industry-wide trend, process and equipment design for continuous operation is one of the most important and frequent tasks of the chemical engineer. It is with this in mind that the present paper is offered as an aid in attacking problems involving either the initial design of continuous stirred-tank reactors or the batch-to-continuous conversion of existing reactors. More specifically, the paper seeks to (1) extend previously published theory on the design of continuous stirred-tank reaction systems for homogeneous liquid-phase reactions, and (2) present experimental data on a first-order reaction, viz., the hydrolysis of acetic anhydride, carried out in such a system, comparing observed and theoretical results.

Previously Published Theory

Several investigators (*4, 7, 9, 11, 13*) have offered variations on the derivation of the purging-time equation for a system of continuous mixing vessels connected in series. The most general is that of Kirillov (*11*), whose equation is

$$C_n = C_o + e^{-\frac{t}{\theta}}\left\{ A_n + A_{n-1}\left(\frac{t}{\theta}\right) + \frac{A_{n-2}}{2!}\left(\frac{t}{\theta}\right)^2 + \cdots + \frac{A_1}{(n-1)!}\left(\frac{t}{\theta}\right)^{n-1} - C_o\left[1 + \left(\frac{t}{\theta}\right) + \frac{1}{2!}\left(\frac{t}{\theta}\right)^2 + \cdots + \frac{1}{(n-1)!}\left(\frac{t}{\theta}\right)^{n-1}\right]\right\} \quad (1)$$

which, for the case when the initial concentration, A, equals zero in each vessel, reduces to

$$\frac{C_n}{C_o} = 1 - e^{-\frac{t}{\theta}}\left[1 + \left(\frac{t}{\theta}\right) + \frac{1}{2!}\left(\frac{t}{\theta}\right)^2 + \cdots + \frac{1}{(n-1)!}\left(\frac{t}{\theta}\right)^{n-1}\right] \quad (2)$$

MacMullin and Weber (*13*) were the first to extend the mathematical analysis to the problem of homogeneous chemical reactions being carried out continuously in a series of stirred-tank reactors (Fig. 1). They derived the steady-state design equations for the cases of first-order reactions and of second- and third-order reactions with equivalent reactant concentrations (Table 1). These authors placed considerable stress on the comparative efficiency or productivity per unit reactor volume obtainable in continuous vs. batch operation. A graphical method has been recently suggested by Tiller (*19*) to solve the telescopic functions used by MacMullin and Weber (*13*) in the preparation of their tables.

Kirillov (*11*) extended the analysis for first-order reactions to include the transient starting-up period as well as the steady-state condition of operation. He offered another derivation of the design equations for second- and third-order reactions with equivalent reactant concentrations, and also derived the steady-state equation for the case of two consecutive first-order reactions (Table 1). In a second paper (*12*), Kirillov presented some experimental data supporting his equation for purging in a

† Present address: 1410 St. Vincent St., Phila. 11, Pa.

TABLE 1. DESIGN EQUATIONS FOR CONTINUOUS STIRRED-TANK REACTORS

Homogeneous Liquid-Phase Reactions with Negligible Volume Change

A. Unidirectional Reactions

Reaction	$-\left(\frac{dC}{dt}\right)_n$	Design Equation for nth Reactor	Eq. No.	Method for n Identical Reactors in Series. Comments.
General	$-\left(\frac{dC}{dt}\right)_n$	$\frac{C_{n-1}}{C_n} = 1 - \left(\frac{dC}{dt}\right)_n \frac{\theta_n}{C_n}$	19	Generic design equation from which all the following are derived.
Zero Order $A \rightarrow xR$	k	$\frac{a_{n-1}}{a_n} = 1 + \frac{k\theta_n}{a_n}$	20	General equation suggested, viz., $D_n = \frac{nk\theta}{a_o}$
First Order $A \rightarrow xR$	$k\,a_n$	$\frac{a_{n-1}}{a_n} = 1 + k\,\theta_n$	21	General equation suggested, viz., $D_n = 1 - (1 + k\,\theta)^{-n}$
Second Order, Equivalent Concentrations $2A \rightarrow xR$ or $A+B \rightarrow xR$	$k\,a_n^2$	$\frac{a_{n-1}}{a_n} = 1 + k\,\theta_n\,a_n$	22	Graphical stepwise solution suggested.
Second Order, Unequivalent Concentrations $A+B(\text{in excess}) \rightarrow xR$	$k\,a_n(E + a_n)$	$\frac{a_{n-1}}{a_n} = 1 + k(E + a_n)\,\theta_n$	23	Graphical stepwise solution suggested.
Third Order, Equivalent Concentrations $3A \rightarrow xR$ or $2A+B \rightarrow xR$ or $A+B+C \rightarrow xR$	$k\,a_n^3$	$\frac{a_{n-1}}{a_n} = 1 + k\,\theta_n\,a_n^2$	24	Graphical stepwise solution suggested.
Third Order, Unequiv. Conc. $\underbrace{A + B + C \rightarrow xR}_{\text{in excess}}$	$k\,a_n(E_1+a_n)(E_2+a_n)$	$\frac{a_{n-1}}{a_n} = 1 + k\,\theta_n(E_1+a_n)(E_2+a_n)$	25	Graphical stepwise solution suggested. $E_1 = (b_o - a_o)$, $E_2 = (c_o - a_o)$
Third Order, Unequiv. Conc. $2A+B(\text{in excess}) \rightarrow xR$	$k\,a_n^2\,(E' + \frac{a_n}{2})$	$\frac{a_{n-1}}{a_n} = 1 + k\theta_n\,a_n\,(E' + \frac{a_n}{2})$	26	Graphical stepwise solution suggested. $E' = (b_o - \frac{a_o}{2})$
Third Order, Unequiv. Conc. $A+2B(\text{in excess}) \rightarrow xR$	$k\,a_n\,(E'' + 2a_n)^2$	$\frac{a_{n-1}}{a_n} = 1 + k\,\theta_n(E'' + 2a_n)^2$	27	Graphical stepwise solution suggested. $E'' = (b_o - 2a_o)$

B. Reversible Reactions

Reaction	$-\left(\frac{dC}{dt}\right)_n$	Design Equation for nth Reactor	Eq. No.	Method for n Identical Reactors in Series, and Comments
$A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} B$	$(k_1 + k_2)\,a_n - k_2 a_o$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 + k_2\left(1 - \frac{a_o}{a_n}\right)\right]\theta_n$	28	Graphical stepwise solution suggested.
$2A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} B$	$(k_1 a_n + \frac{k_2}{2})\,a_n - \frac{k_2 a_o}{2}$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 a_n + \frac{k_2}{2}\left(1 - \frac{a_o}{a_n}\right)\right]\theta_n$	29	Graphical stepwise solution suggested.
$2A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} 2B$	$k_1\,a_n^2 - k_2(a_o - a_n)^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 a_n - k_2\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	30	Graphical stepwise solution suggested.
$A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} 2B$	$k_1\,a_n - k_2[2(a_o - a_n)]^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 - 4k_2\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	31	Graphical stepwise solution suggested.
$A+B\ (\text{in excess}) \underset{(2)}{\overset{(1)}{\rightleftharpoons}} C$	$k_1 a_n(E + a_n) - k_2(a_o - a_n)$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1(E + a_n) + k_2\left(1 - \frac{a_o}{a_n}\right)\right]\theta_n$	32	Graphical stepwise solution suggested.
$A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} B+C$	$k_1 a_n - k_2(a_o - a_n)^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 - k_2\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	33	Graphical stepwise solution suggested.
$2A \underset{(2)}{\overset{(1)}{\rightleftharpoons}} B+C$	$k_1 a_n^2 - k_2(\frac{a_o - a_n}{2})^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1 a_n - \frac{k_2}{4}\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	34	Graphical stepwise solution suggested.
$A+B\ (\text{in excess}) \underset{(2)}{\overset{(1)}{\rightleftharpoons}} 2C$	$k_1 a_n(E + a_n) - k_2[2(a_o - a_n)]^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1(E + a_n) - 4k_2\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	35	Graphical stepwise solution suggested.
$A+B\ (\text{in excess}) \underset{(2)}{\overset{(1)}{\rightleftharpoons}} C+D$	$k_1 a_n(E + a_n) - k_2(a_o - a_n)^2$	$\frac{a_{n-1}}{a_n} = 1 + \left[k_1(E + a_n) - k_2\frac{(a_o - a_n)^2}{a_n}\right]\theta_n$	36	Graphical stepwise solution suggested.

system of seven vessels, and also, his equations for first- and second-order reactions in a single continuous reactor.

Denbigh (*4*) discussed the comparison of output per unit volume of reaction space in batch and continuous stirred-tank reactors, and pointed out that the greatest over-all productivity for a given total volume of continuous reactors is obtained when the reactors increase in volume from the first, for all reactions of order greater than unity. He also considered the problem of the comparative yields of useful product obtainable by batch and continuous operation in the case of competing reactions, and showed that this yield is controllable to some extent by choice of a batch or

TABLE 1. (Continued)

C. Simultaneous Reactions

Reactions			$-\left(\frac{dC}{d\tau}\right)_n$	Design Equation for nth Reactor	Eq. No.	Method for n Identical Reactors in Series, and Comments
$A \rightarrow \alpha R$ (1) $A \rightarrow \gamma S$ (2)			$(k_1 + k_2)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 + k_2)\,\theta_n$	37	General equation suggested, viz., $D_n = 1 - \left[1 + (k_1+k_2)\,\theta_n\right]^{-n}$
$A \rightarrow \alpha R$ (1) $2A \rightarrow \gamma S$ (2)			$(k_1 + k_2 a_n)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 + k_2 a_n)\,\theta_n$	38	Graphical stepwise solution suggested.
$2A \rightarrow \alpha R$ (1) $2A \rightarrow \gamma S$ (2)			$(k_1 + k_2)\, a_n^2$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 + k_2)\, a_n\, \theta_n$	39	Graphical stepwise solution suggested.
$A + B$(in excess) $\rightarrow \alpha R$ (1) $A + B$(in excess) $\rightarrow \gamma S$ (2)			$(k_1 + k_2)(E + a_n)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1+k_2)(E+a_n)\,\theta_n$	40	Graphical stepwise solution suggested. If concentrations of A and B were equivalent, Eq. (39) would then apply.
$A \rightarrow \alpha R$ (1) $A+B \rightarrow \gamma S$ (2)	If A is reactant of interest		$(k_1 + k_2 b_n)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 + k_2\, b_n)\,\theta_n$ $b_n = \frac{-Q + \sqrt{Q^2 + 4\,\frac{k_1}{k_2}\, b_{n-1}}}{2}$ where $Q = a_{n-1} - b_{n-1} - a_n + \frac{k_1}{k_2}$	41	Algebraic stepwise solution suggested.
	If B is reactant of interest		$k_2\, a_n\, b_n$	$\frac{b_{n-1}}{b_n} = 1 + k_2\,\theta_n\, a_n$ $a_n = a_{n-1} - (\frac{k_1}{k_2 b_n} + 1)(b_{n-1} - b_n)$	42	Algebraic stepwise solution suggested.
$2A \rightarrow \alpha R$ (1) $A+B \rightarrow \gamma S$ (2)	If A is reactant of interest		$(k_1 a_n + k_2 b_n)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 a_n + k_2 b_n)\,\theta_n$ $b_n = \frac{-Q + \sqrt{Q^2 + 4\,\frac{k_1}{k_2}\, a_n\, b_{n-1}}}{2}$ $Q = a_{n-1} - b_{n-1} + (\frac{k_1}{k_2} - 1)\, a_n$	43	Algebraic stepwise solution suggested
	If B is reactant of interest		$k_2\, a_n\, b_n$	$\frac{b_{n-1}}{b_n} = 1 + k_2 a_n \theta_n$ $a_n = \frac{(a_{n-1} - b_{n-1} + b_n)}{(\frac{b_{n-1}}{b_n} - 1)\,\frac{k_1}{k_2} + 1}$	44	Algebraic stepwise solution suggested
$A+B \rightarrow \alpha R$ (1) $A+C \rightarrow \gamma S$ (2)	If A is reactant of interest		$(k_1 b_n + k_2 c_n)\, a_n$	$\frac{a_{n-1}}{a_n} = 1 + (k_1 b_n + k_2 c_n)\,\theta_n$ $\frac{b_n}{\frac{k_2}{k_1} c_n + b_n} = \frac{b_{n-1} - b_n}{a_{n-1} - a_n}$ $\frac{c_n}{\frac{k_1}{k_2} b_n + c_n} = \frac{c_{n-1} - c_n}{a_{n-1} - a_n}$	45	Algebraic stepwise solution suggested
	If B is reactant of interest		$k_1\, a_n\, b_n$	$\frac{b_{n-1}}{b_n} = 1 + k_1 \theta_n a_n$ $a_n = a_{n-1} - (\frac{b_{n-1}}{b_n} - 1)(\frac{k_2}{k_1} c_n + b_n)$ $\frac{c_n}{(\frac{k_1}{k_2} b_n + c_n)} = \frac{c_{n-1} - c_n}{a_{n-1} - a_n}$	46	Algebraic stepwise solution suggested.

continuous system, and also, within a continuous system, by the ratio of the volumes of the consecutive reactors in the series. In a later paper (*5*), Denbigh derived the equations describing the kinetics of steady-state polymerization in a single continuous stirred-tank reactor, and in his most recent contribution (*6*), he presented a general discussion of the properties of reactions being carried out continuously in stirred-tank reactors. Stead, Page, and Denbigh (*18*) described an experimental method for the determination of reaction velocity constants using a continuous stirred-tank reactor.

In a symposium on continuous flow processes, MacMullin and Weber (*14*),

TABLE 1. (Continued)

D. Consecutive Reactions

Reactions		$-\left(\frac{dC}{dt}\right)_n$	Design Equation for nth Reactor	Eq. No.	Method for n Identical Reactors in Series, and Comments
(1) (2) A → B → C	Referring to A	$k_1 a_n$	$\frac{a_{n-1}}{a_n} = 1 + k_1 \theta_n$	47	General equation suggested, viz., $D_n = 1 - (1 + k_1\theta_n)^{-n}$
	Referring to B	$k_2 b_n - k_1 a_n$	$\frac{b_{n-1}}{b_n} = 1 + (k_2 - \frac{k_1 a_n}{b_n})\theta_n$	48	Algebraic stepwise solution suggested
	Referring to C	$-k_2 b_n$	$\frac{c_{n-1}}{c_n} = 1 - k_2 \frac{b_n}{c_n}\theta_n$	49	Algebraic stepwise solution suggested
(1) (2) (3) A → B → C → D	Referring to A and B				Eqs. (47) and (48) apply, respectively.
	Referring to C	$k_2 c_n - k_3 b_n$	$\frac{c_{n-1}}{c_n} = 1 + (k_2 - \frac{k_3 b_n}{c_n})\theta_n$	50	Algebraic stepwise solution suggested.
	Referring to D	$-k_3 c_n$	$\frac{d_{n-1}}{d_n} = 1 - k_3 \frac{c_n}{d_n}\theta_n$	51	Algebraic stepwise solution suggested.
(1) (2) A+B(in excess) → C → D	Referring to A	$k_1 a_n(E + a_n)$	$\frac{a_{n-1}}{a_n} = 1 + k_1 (E + a_n)\theta_n$	52	Graphical stepwise solution suggested.
	Referring to C	$k_2 c_n - k_1 a_n(E+a_n)$	$\frac{c_{n-1}}{c_n} = 1 + \left[k_2 - \frac{k_1 a_n(E+a_n)}{c_n}\right]\theta_n$	53	Algebraic stepwise solution suggested.
	Referring to D	$-k_2 c_n$	$\frac{d_{n-1}}{d_n} = 1 - k_2 \frac{c_n}{d_n}\theta_n$	54	Algebraic stepwise solution suggested.
(1) (2) A → B + C → D	Referring to A				Eq. (47) applies.
	Referring to B or C	$k_2 b_n^2 - k_1 a_n$	$\frac{b_{n-1}}{b_n} = 1 + (k_2 b_n - k_1 \frac{a_n}{b_n})\theta_n$	55	Algebraic stepwise solution suggested.
	Referring to D	$-k_2 b_n^2$	$\frac{d_{n-1}}{d_n} = 1 - k_2 \frac{b_n^2}{d_n}\theta_n$	56	Algebraic stepwise solution suggested.
(1) (2) A+E(in excess) → C+D → E	Referring to A				Eq. (52) applies.
	Referring to C or D (must be equivalent).	$k_2 c_n^2 - k_1 a_n(E+a_n)$	$\frac{c_{n-1}}{c_n} = 1 + \left[k_2 c_n - k_1 \frac{a_n(E+a_n)}{c_n}\right]\theta_n$	57	Algebraic stepwise solution suggested.
	Referring to E	$-k_2 c_n^2$	$\frac{e_{n-1}}{e_n} = 1 - k_2 \frac{c_n^2}{e_n}\theta_n$	58	Algebraic stepwise solution suggested

Olsen and Lyons (*16*), and Brothman, Wollan and Feldman (*2*) discussed some advantages and disadvantages of batch operation compared with continuous operation using stirred-tank reactors. The latter group of authors also presented design equations for a series of continuous reactors of the draft-tube type, in which internal recirculation is highly channelized. These equations apply also to a continuous pipe-line or tubular reactor in which part of the flow is recycled.

In a recent paper, MacMullin (*15*) pointed out that batch operation and continuous operation with stirred-tank reactors lead to different distributions of reaction products in the case of consecutive reactions. He illustrated the point with some calculations on the chlorination of benzene.

Design Equations

Consider a homogeneous liquid-phase reaction being carried out continuously in a system of reaction vessels connected in series, so that the effluent from the first reactor is the feed to the second, the effluent from the second the feed to the third, and so on, as illustrated schematically in Figure 1. These reactors could, of course, be compartments within a single vessel. Each reactor is equipped with an agitator which provides essentially homogeneous mixing, thus maintaining the reactant concentrations uniform throughout the vessel. The effluent from any reactor, then, has the same composition as the contents of that reactor. A material balance over the nth reactor in the system, with respect to any one reactant, under steady-state conditions, results in the following general design equation, applicable to any reaction.

$$C_{n-1}F_{n-1} = C_nF_n - \left(\frac{dC}{dt}\right)_n V_n \qquad (3)$$

where

C_{n-1} = molar concentration of reactant in $(n-1)$th reactor

C_n = molar concentration of reactant in nth reactor

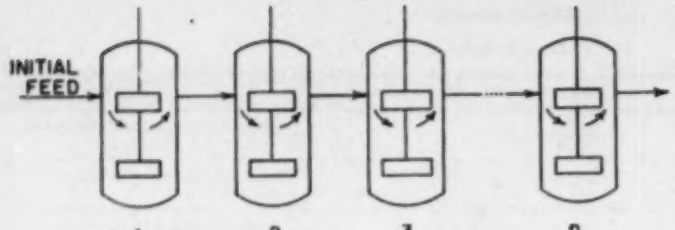

Fig. 1. Continuous Stirred-Tank Reactors Operated in Series.

$-\left(\frac{dC}{dt}\right)_n$ = rate of reaction of this reactant in nth reactor in moles per unit volume per unit time

F_{n-1} = volumetric effluent rate from $(n-1)$th reactor

F_n = volumetric effluent rate from nth reactor

V_n = volume occupied by reaction medium in nth vessel

If any additional stream, e.g., recycle material or fresh reactant, is introduced, or a portion of the total flow is withdrawn as a side stream, at the nth reactor, then the design equation must include an additional term to take this into account, i.e.,

$$C_{n-1}F_{n-1} + C_sF_s = C_nF_n - \left(\frac{dC}{dt}\right)_n V_n \qquad (4)$$

where

C_s = molar concentration of reactant in side stream

F_s = volumetric flow rate of side stream, to be taken as positive if the stream is entering system, and negative if it is leaving

Equation (3), which represents the usual practice where no side stream is used, may be written in the form

$$\frac{C_{n-1}}{C_n} \cdot \frac{F_{n-1}}{F_n} = 1 - \left(\frac{dC}{dt}\right)_n \frac{\theta_n}{C_n} \qquad (5)$$

where

$\theta_n = V_n/F_n$ = nominal holding time in the nth reactor

or, since the volumetric flow rate is inversely proportional to the density of the stream, ρ, then

$$\frac{C_{n-1}}{C_n} \cdot \frac{\rho_n}{\rho_{n-1}} = 1 - \left(\frac{dC}{dt}\right)_n \frac{\theta_n}{C_n} \qquad (6)$$

In order to use Equation (5) or (6) for design calculations, the relationship between the density and the concentration must, of course, be known for the particular feed composition to be used. Fortunately, it is the general case with liquid-phase reactions that the density changes occurring are relatively small, and when this condition exists the volumetric rate of throughput, F, may be taken to be the same throughout the system and equal to the feed rate to the first reactor. Equations (5) and (6) then become

$$\frac{C_{n-1}}{C_n} = 1 - \left(\frac{dC}{dt}\right)_n \frac{\theta_n}{C_n} \qquad (7)$$

Because of its importance, Equation (7) is used as the generic design equation in the following treatment.

All the design equations given in Table 1 were obtained by substituting the rate of reaction, $-(dC/dt)_n$, expressed as a function of the reactant concentrations for the particular type reaction in question, into Equation (7), the general material balance equation. It should be understood that an exactly analogous table could be compiled based on Equation (5) or (6) by making these same substitutions for $-(dC/dt)_n$ in these equations. Thus the exact design equations for variable volume reactions are readily obtainable if needed.

As an illustration of the derivation of the equations of Table 1, consider the case of a second-order reaction in which the reactants are not present in stoichiometrically equivalent concentrations. Such a reaction may be represented simply by

$A + B$(in excess) → Reaction Products

Here

$$-\left(\frac{dC}{dt}\right)_n = ka_nb_n \qquad (8)$$

where

k = reaction velocity constant

a_n = molar concentration of limiting reactant A in nth reactor

b_n = molar concentration of nonlimiting reactant B in nth reactor

The design equation may be written in terms of the concentration of either reactant A or B. Taking the limiting reactant, A, as the one which is of par-

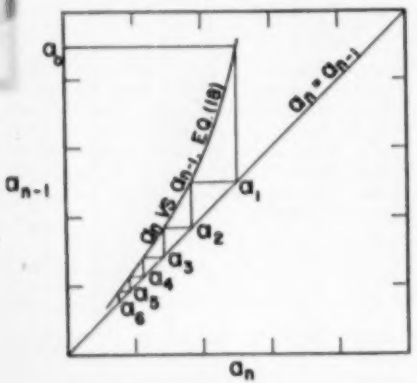

Fig. 2. Graphical Solution of Design Equation for Higher-Order Reactions.

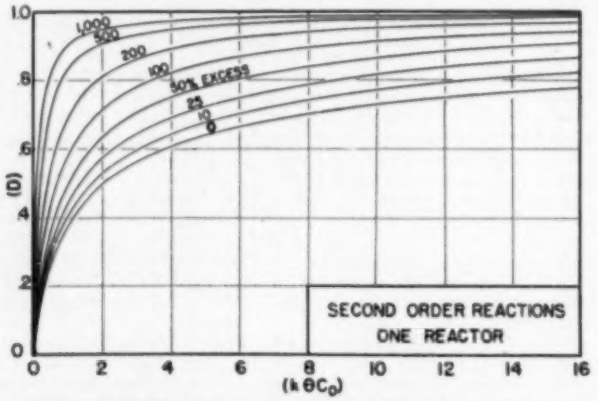

Fig. 3. Second-Order Reactions with Unequivalent Concentrations. Degree of completion vs. dimensionless group ($k\theta C_0$) for various per cents excess of nonlimiting reactant.

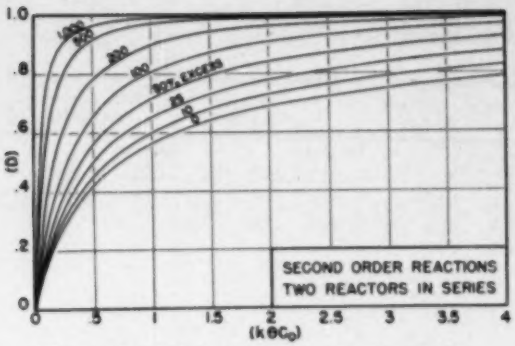

Fig. 4. Second-Order Reactions with Unequivalent Concentrations.
Degree of completion vs. dimensionless group ($k\theta C_o$) for various per cents excess of nonlimiting reactant.

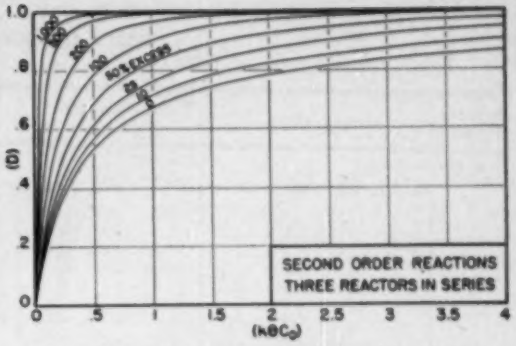

Fig. 5. Second-Order Reactions with Unequivalent Concentrations.
Degree of completion vs. dimensionless group ($k\theta C_o$) for various per cents excess of nonlimiting reactant.

ticular interest, Equation (7) then becomes, for this case,

$$\frac{a_{n-1}}{a_n} = 1 + kb_n\theta_n \qquad (9)$$

b_n may now be expressed in terms of a_n by introducing E, the absolute excess (as distinguished from the per cent excess) concentration of B above that equivalent to the concentration of A. Throughout the entire course of the reaction E is constant and equal to the absolute excess used in the feed to the system. Thus

$$E = b_o - a_o = b_n - a_n \qquad (10)$$

where

a_o = molar concentration of limiting reactant A entering system
b_o = molar concentration of reactant B entering system

Substituting for b_n in Equation (9), the design equation for second-order reactions with unequivalent reactant concentrations is obtained.

$$\frac{a_{n-1}}{a_n} = 1 + k\theta_n(E + a_n) \qquad (11)$$

While many design equations of Table 1 for more complex types of reaction, such as reversible, simultaneous, and consecutive reactions, are themselves more complicated, nevertheless they are all obtained in the same straightforward manner as the above example, viz., by substitution of the appropriate expression for $-(dC/dt)_n$ for the rate of the reaction under consideration, referred to the reactant of interest, into the generic design equation, Equation (7).

Application of Design Equations to n Reactors in Series. If the holding time, θ_n, and/or the reaction velocity constant, k, vary from one reactor to the next, in a system of two or more vessels operated in series, then the application of the design equations of Table 1 must be carried out stage by stage. However, in typical practice the reaction velocity constant is the same throughout the system, and all the reactors are of the same size so that, under the condition of Equation (7) of negligible density change in the reacting medium, the holding time is the same in each of the reactors, i.e., $\theta_1 = \theta_2 = \ldots = \theta_n = \theta$. It is with this system that the following discussion deals.

In the cases of zero-order and first-order reactions general equations for the degree of completion, D_n, for a series of reactors, may be derived from the design equations for the nth reactor. Thus, for zero-order reactions

$$\frac{a_{n-1}}{a_n} = 1 + \frac{k\theta}{a_n} \qquad (12)$$

or, rearranging,

$$a_{n-1} - a_n = k\theta \qquad (13)$$

Whence,

$$a_o - a_n = nk\theta \qquad (14)$$

Again rearranging,

$$\frac{a_n}{a_o} = 1 - \frac{nk\theta}{a_o} \qquad (15)$$

Since by definition

$$D_n = 1 - \frac{a_n}{a_o}$$

the general design equation for D_n for n reactors in series then becomes

$$D_n = \frac{nk\theta}{a_o} \qquad (16)$$

For first-order reactions, MacMullin and Weber (*13*) have shown that the analogous equation for D_n is

$$D_n = 1 - (1 + k\theta)^{-n} \qquad (17)$$

However, for higher-order reactions and for most reversible, simultaneous, and consecutive reactions, the design equations are not particularly convenient to write or to use as general expanded expressions for n reactors. Consequently they are applied to a series of reactors by a stagewise operation, either algebraic or graphical. The algebraic attack is self-evident, consisting simply of starting with the known values of the operating variables and the reactant concentration in the feed to the first reactor, C_o, solving the design equations (Table 1) for the reactant concentration leaving the first reactor and entering the second reactor, C_1, then using this value of C_1 as C_{n-1} to solve the equation again, thus obtaining C_2, and so on to C_n for the desired number of reactors in series.

A simple and rapid graphical solution for any number of reactors in series can be used to advantage, especially for many of the more complex design equations (*see* last column of Table 1). This procedure will be demonstrated for the case of second-order reactions with one reactant present in excess. The design equation here, for the nth reactor, is:

$$\frac{a_{n-1}}{a_n} = 1 + k\theta(E + a_n) \qquad (18)$$

Using the given values of k, θ, and E, which all remain constant throughout a system of identical reactors, Equation (18) is plotted as a_{n-1} vs. a_n (Fig. 2). This requires no quadratic solutions as does the algebraic stepwise method, in which the equation must be repeatedly solved for a_n. Rather, in this case, a series of arbitrary values of a_n are chosen and the equation solved directly for the corresponding values of a_{n-1}. These are plotted to form the operating line. The 45° diagonal line, i.e., $a_n = a_{n-1}$, is then drawn in.

Now starting at the value of the concentration a_o in the feed to the first reactor, a horizontal line is drawn to the operating line, and from this point, vertical, then horizontal lines are alternately drawn between the operating line

TABLE 2. EXPERIMENTAL RESULTS

Reactor System	One Reactor				Two Reactors in Series			Three Reactors in Series			Four Reactors in Series			Five Reactors in Series		
Run No.	Reactor No.	kθ	D_a	D_t	Reactor Nos.	D_a	D_t	Reactor Nos.	D_a	D_t	Reactor Nos.	D_a	D_t	Reactor Nos.	D_a	D_t
	1	.379	.258	.274	1-2	.462	.476	1-3	.624	.623	1-4	.730	.728	1-5	.807	.806
	2	.390	.275	.279	2-3	.493	.482	2-4	.636	.626	2-5	.740	.734			
1	3	.392	.301	.291	3-4	.498	.481	3-5	.641	.630						
	4	.387	.280	.278	4-5	.486	.486									
	5	.408	.285	.288												
	1	.483	.331	.325	1-2	.556	.547	1-3	.699	.696						
2	2	.496	.336	.330	2-3	.550	.551									
	3	.498	.324	.330												
	1	.711	.408	.415	1-2	.642	.662	1-3	.796	.805						
3	2	.730	.415	.422	2-3	.666	.666									
	3	.733	.430	.423												
	1	.189	.153	.159	1-2	.290	.291	1-3	.397	.402	1-4	.489	.497	1-5	.576	.575
	2	.186	.162	.157	2-3	.288	.289	2-4	.396	.402	2-5	.498	.496			
4	3	.186	.150	.157	3-4	.280	.290	3-5	.401	.402						
	4	.188	.153	.158	4-5	.295	.291									
	5	.187	.168	.158												
	1	.214	.164	.176	1-2	.314	.320	1-3	.430	.438	1-4	.536	.537	1-5	.616	.618
	2	.210	.180	.174	2-3	.318	.313	2-4	.446	.438	2-5	.541	.536			
5	3	.211	.169	.174	3-4	.325	.320	3-5	.441	.438						
	4	.213	.188	.176	4-5	.328	.320									
	5	.212	.173	.175												
	1	1.209	.550	.547	1-2	.795	.793	1-3	.903	.905	1-4	.958	.956	1-5	.977	.980
6	2	1.183	.544	.542	2-3	.785	.790	2-4	.906	.904	2-5	.948	.956			
	3	1.173	.529	.540	3-4	.794	.790									
	1	1.288	.557	.563	1-2	.805	.807	1-3	.915	.914	1-4	.960	.962	1-5	.986	.983
7	2	1.260	.560	.558	2-3	.808	.804	2-4	.910	.913						
	3	1.249	.563	.556												
	1	1.380	.583	.580	1-2	.823	.821	1-3	.924	.924	1-4	.968	.968	1-5	.987	.986
	2	1.350	.575	.575	2-3	.817	.818	2-4	.923	.923	2-5	.968	.968			
8	3	1.338	.570	.572	3-4	.819	.819	3-5	.925	.924						
	4	1.357	.580	.576	4-5	.826	.821									
	5	1.369	.585	.578												
9	1	7.80	.882	.886	1-2	.989	.987	1-3	.998	.999	1-4	1.00	1.00	1-5	1.00	1.00

TABLE 3. OPERATING DATA

Run No.	Temp.	Reaction Velocity Constant, k	Feed Rate, F	Agitator Speed	Dissolving Column Length	Total Acid Concentration
1	15.0°C.	0.0806/min.	378.cc/min.	325.rpm	22. in.	0.216 N
2	25.0	0.1580	582	325	22	0.143
3	25.0	0.1580	395	325	22	0.137
4	10.0	0.0567	555	125	22	0.108
5	10.0	0.0567	490	125	22	0.052
6	40.0	0.380	575	125	22	0.095
7	40.0	0.380	540	125	22	0.0925
8	40.0	0.380	500	125	4	0.187
9	40.0	0.380	88.5	125	4	0.202

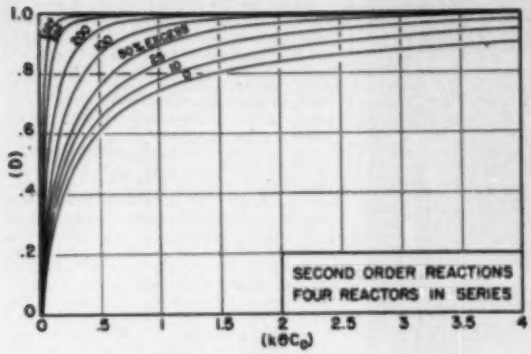

Fig. 6. Second-Order Reactions with Unequivalent Concentrations.
Degree of completion vs. dimensionless group ($k\theta C_o$) for various per cents excess of nonlimiting reactant.

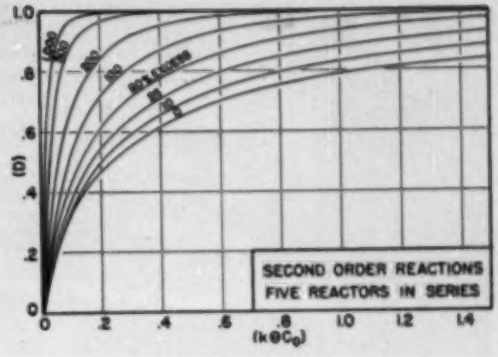

Fig. 7. Second-Order Reactions with Unequivalent Concentrations.
Degree of completion vs. dimensionless group ($k\theta C_o$) for various per cents excess of nonlimiting reactant.

and the 45° line (illustrated in Fig. 2), until the desired value of the effluent concentration, a_n, is reached. Thus a_n, and hence the degree of completion, D_a, is readily obtained for any number of reactors, or vice versa. It can be seen that this graphical stepping-off process amounts to the repeated algebraic solving of Equation (18) using the value of a_n obtained in each solution as the value of a_{n-1} in the subsequent solution. Moreover, this solution also presents immediately a graphical picture of the progress of the reaction along the series of reactors.

Consider now the solution of the design problem in which the quantity sought is the nominal holding time, θ, from which is obtained either (1) the throughput capacity, F, of a given system of reactors at a specified degree of completion, D, or (2) the reactor volume, V, necessary to obtain a certain degree of completion at a given rate of throughput with a given number of reactors in series. When the nominal holding time, θ, is the unknown quantity, a trial-and-error solution is required, regardless of whether the algebraic or graphical method is used. In the graphical method, an estimated value of θ is used to plot the operating line, and the solution for the effluent concentration, a_n, is carried out for the given number of reactors. Then by comparing this value of a_n with that required by the values of D, specified in the problem, a better estimate of θ is made, from which a new operating line is plotted, and the new solution is stepped off. This process is repeated until the correct value of θ is indicated by the agreement of the value of D so obtained with the value stated by the problem. In those cases where E, the excess of the nonlimiting reactant, is the unknown quantity this same procedure is applicable.

Though this method of solving for θ or E involves trial and error and replotting of the curve, it is still far more rapid and less subject to time-consuming mistakes than the alternative trial-and-error application of the algebraic stepwise process for the same problem, in which for each estimated value of θ it is necessary to go through the whole series of quadratic solutions of the equation to obtain a_n for the specified value of the number of reactors. The advantage of the graphical method becomes greater as the number of reactors is increased.

In the case of some of the more complex design equations for simultaneous and consecutive reactions, the graphical stepwise process just described is not applicable (*see* Table 1). The reasons become apparent in each case upon examination of the nature of the design equations in question. There appears in these design equations a concentration term for a reactant other than the reactant of interest, and this concentration term is not a constant throughout the system and also is not readily expressed in terms of the concentration of the reactant of interest. To take a specific instance, in Equation (41), the term b_n appears for the concentration of reactant B in the nth vessel. This concentration has a different value in each reactor. Consequently, it is not feasible to plot Equation (41) as a_n vs. a_{n-1} directly since the values of b_n for each reactor would first have to be calculated, and in doing this the corresponding values of a_n would be obtained simultaneously in the stage-by-stage algebraic solution. Thus in this case, starting with the given values of the feed concentrations, a_o and b_o, the concentrations of both reactants A and B leaving the first reactor are calculated, then these values are used to calculate the concentrations leaving the second reactor, and so on in an algebraic stepwise procedure.

Methods presented here for the solution of engineering design problems for reactions carried out continuously in stirred-tank systems are applicable to any homogeneous reaction system for which the mechanisms and the rates of the individual reactions are known. Complex reactions which are comprised of several simultaneous, reversible, or consecutive reactions may be treated in the same manner if the mechanisms and the velocity constants are known for those individual reactions which determine the over-all rate. Conversely, laboratory continuous stirred-tank reactors should be useful in studying the mechanism of reactions.

Special Case of Second-Order Reactions with Unequivalent Concentrations. The case of second-order reactions where reactant concentrations are not stoichiometrically equivalent is of such practical importance that a graphical presentation of the design relationships is offered in Figures 3-7. These curves are analogous to those of MacMullin and Weber (*13*) for the case of equivalent reactant concentrations. Here the degree of completion, D_a, is determined by the number of reactors in series, n, the dimensionless group ($k\theta C_o$), and the amount of the excess of nonlimiting reactant which is used. The per cent excess of the nonlimiting reactant in the feed to the first reactor, given by $100\ E/C_o$, was chosen as a convenient and significant parameter to use in showing this latter effect in the graphical presentation. Thus Figure 5, for instance, clearly shows the effect of this per cent excess on the D_a vs. ($k\theta C_o$) curve for a system of three equal-volume reactors in series. Both D_a and C_o in these graphs refer to the limiting reactant.

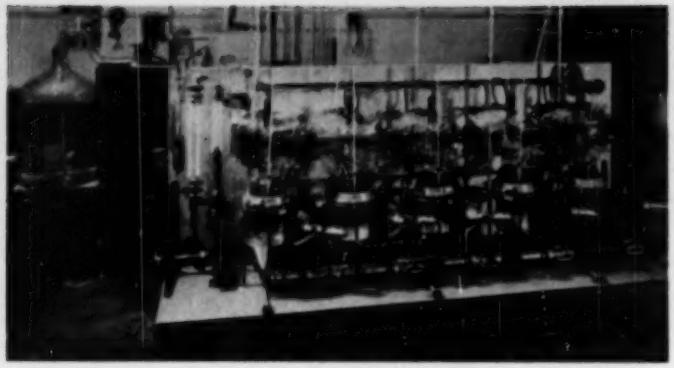

Fig. 8. Experimental Apparatus.

Experimental

A number of experiments were carried out where a first-order reaction was used, viz., the hydrolysis of acetic anhydride, in order to compare the results obtained with those predicted by theory. Rates of throughput, temperature level, and therefor the reaction velocity constant, and the number of vessels operated in series were varied.

Apparatus. Five 1800 cc. Ace Glass high pressure Pyrex autoclaves (Figs. 8, 9) are operated in series. The paddle agitator, *B*, guided by the ground glass bearing, *C*, directs the liquid downward, and was rotated at 125 or at 325 rev./min. (Table 3). Baffles, *E*, are placed inside the vessel, *A*. Reaction solution entering through neck 4 is led to the bottom of the reactor by the feed tube, *D* (Inside Diameter = 3.5 mm.), and leaves at the top through neck 2. A mercurial thermoregulator, inserted through neck 1, operates, through a relay, a 250-watt infrared lamp directed on the side of the vessel to maintain a constant temperature (±.01° C.), registered on a thermometer in neck 3. Cold water sprayed through a perforated ring just below the flange clamp and drained off into the funnel provides cooling when required. Thus individual temperature control is provided for each vessel.

A 1-¾-in. diameter dissolving column, either 4 in. or 22 in. long, depending on the feed rate and temperature being used, and packed with ¼-in.-porcelain Raschig rings, provides solution and mixing of the acetic anhydride in the water to form a homogeneous feed to the first reactor.

Operating Procedure. The system is operated at constant temperature and flow rates for a period of at least fifteen times the holding time, θ, before taking samples, to insure that the original contents, viz., either water or reacted solution from the previous run, have been purged (*9, 11*) and steady-state concentrations attained in all reactors.

The analytical procedure of Caudri (*3*) and Vles (*20*) was used to determine the steady-state concentrations of unreacted acetic anhydride in the feed to the system and in the effluent from each reactor. Total acid concentration (acetic acid plus acetic anhydride expressed as its equivalent in acetic acid) at steady state is the same throughout the system and is determined by collecting a sample of the effluent from the last reactor, allowing time for its complete hydrolysis, and titrating a weighed portion with 0.025-0.05 N. NaOH using phenolphthalein as indicator. To determine the acetic anhydride concentrations, at the entrance to the first reactor and at the exit of each reactor duplicate samples are withdrawn via three-way stopcocks into tared flasks containing 15 to 20 times the quantity of saturated aniline-water required to react with the sample. The anhydride rapidly acetylates the aniline, and the weighed samples are then titrated to determine the acetic acid.

Results

Experimental values of the degree of completion, D_e, are calculated by the equation

$$D_e = 1 - \frac{C_a}{C_o} \qquad (59)$$

where C_a and C_o refer to the molar concentrations of the acetic anhydride in

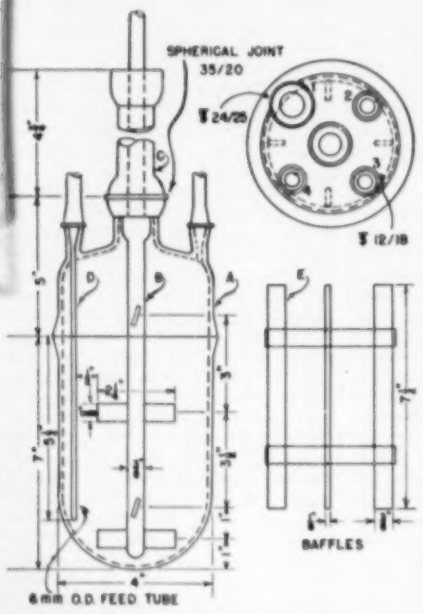

Fig. 9. Diagram of Experimental Continuous Reactor.

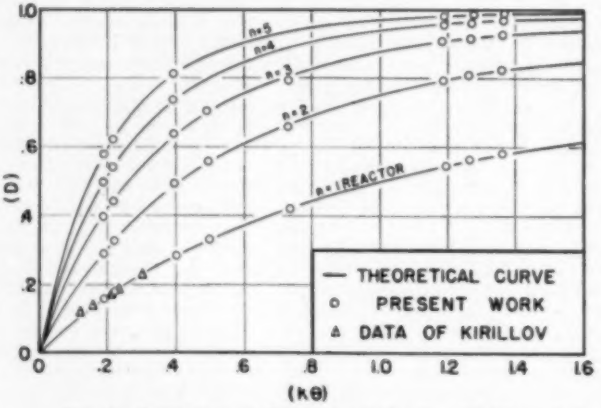

Fig. 10. Comparison of Experimental Results with Theoretical Curves.

the effluent and in the feed stream. From the data of a single run, an independent value of D_e for a single reactor may be calculated for each of the five reactors in the series (Table 2). Similarly, four independent values of D_e for two reactors in series are obtained by considering the five reactors as consisting of four two-reactor systems, viz., 1-2, 2-3, 3-4, and 4-5. Three values of D_e for three-reactor systems, two for four-reactor systems, and one for five reactors in series are analogously obtained. Thus, D_e for the three-vessel system comprised of reactors 2, 3, and 4, for example, is calculated by

$$D_e = 1 - \frac{C_4}{C_1} \qquad (60)$$

where C_4 refers to the effluent from reactor 4 and C_1 to that from reactor 1, which is the feed to reactor 2.

Theoretical degrees of completion, D_t, are calculated by the equation

$$D_t = 1 - \frac{1}{(1+k\theta_1)(1+k\theta_2)\ \ldots\ (1+k\theta_n)} \qquad (61)$$

using the actual values of $k\theta_1$, $k\theta_2$, etc., employed in the run (*13*). The slight variation in $(k\theta)$ from one reactor to another within the same experiment is due to the vessels having slightly different capacities, and hence holding times, θ. Table 3 lists the important operating data for each run. The reaction velocity constants, k, at 10° C. and 15° C. were calculated by means of the Arrhenius equation,

$$ln\frac{k_2}{k_1} = A\frac{T_2 - T_1}{T_2 T_1}$$

evaluating A from two values of k reported in the literature (*3, 10, 17, 20*), viz., $k_{0°} = 0.0258$ and $k_{25°} = 0.1580$. The value of k at 40° C., $k_{40°} = 0.380$, was determined by batch experiments, using the analytical procedure described above. From batch experiments at 15° C. and 25° C., values of k were obtained which agreed with the known values within 0.3%.

The averages, within each run, of the values of the experimental degree of completion, D_e, for the systems of one, two, three, four and five reactors in series, are shown in Figure 10 along with the theoretically computed curves. In the case of Run No. 9, the points lie off-scale at a value $k\theta$ equals 7.8. The average per cent deviation of the experimental values from those calculated by Equation (61) is only 0.4%. Results obtained by Kirillov (*12*) for the continuous hydrolysis of methyl acetate in a single 250 cc. stirred round-bottom flask are also shown in Figure 10.

Experimental Results Discussed

Using systems of from one to five continuous reactors operated in series, it has been shown that the experimental values of the degree of completion, D_e, agree well with the theoretical values, D_t, for a first-order reaction. The fact that Kirillov's results, obtained with a different reaction in quite another type of reactor also agree with the theory, offers further evidence that continuous reaction systems may be correctly designed by use of the theoretical equations.

It is considered to be of some importance that the intensity of agitation used, expressed on the basis of energy input per unit volume calculated either from the correlation of Hooker (*8*) or by the equation of White and Brenner (*21*) is well below that encountered in typical commercial practice (*1*). Thus, the agitation required for the essentially homogeneous mixing which was obtainable in the present work was not excessive.

Notation

A,B,C,D,E = reactants A,B,C,D, and E

a,b,c,d,e = molar concentrations of reactants A,B,C,D, and E

A = initial concentration in system, at time $t = 0$, in Kirillov's equations

A = constant in Arrhenius equation

C = molar concentration of component of interest

$-\left(\frac{dC}{dt}\right)$ = rate of reaction of reactant of interest in moles per unit volume per unit time

D = degree of completion of a reaction, defined as $1 - \frac{C_n}{C_o}$. Subscripts e and t refer to experimental and theoretical, respectively

E = absolute excess concentration of nonlimiting reactant over that equivalent to limiting reactant

e = base of natural logarithms

F = volumetric rate of flow

k = specific reaction velocity constant

n = number of vessels operated in series

R,S = products of reaction

z,γ = number of moles of products R and S, respectively

T = absolute temperature, °K.

t = time

V = vessel volume occupied by reaction medium

ρ = liquid density

$\theta = V/F$ = nominal holding time in a single vessel.

Subscripts:

$_n$ = nth vessel

$_{n-1}$ = $(n-1)$th vessel

$_o$ = feed to first vessel

$_{1,2,3}$ = first, second, or third vessel, respectively

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KINETICS IN TUBULAR FLOW REACTOR

HYDROGENATION OF ETHYLENE OVER COPPER-MAGNESIA CATALYST

RAYMOND WYNKOOP† and RICHARD H. WILHELM

Princeton University, Princeton, New Jersey

The catalytic hydrogenation of ethylene over copper-magnesia catalyst was studied experimentally and theoretically as an example of the application of chemical kinetics to a continuous flow tubular reactor. Most experiments were isothermal; a few experiments were permitted to assume modest temperature variations. Experimental conditions were varied over the following ranges: hydrogen concentration: 32.6 to 95.2 per cent; temperature: 9 to 79° C.; space velocity: 0.20×10^{-4} to 32.0×10^{-4} total moles/(cc.)(sec.); catalyst particle size: 0.108 to 0.279 cm. diameter. Kinetic equations for the flow system were developed and the experimental data were found to correspond to a first-order reaction with respect to hydrogen. The effect of temperature is expressed in the Arrhenius equation as follows:

$$k'' = 5960e^{-13{,}320/RT}$$

The precision of measurement of the rate constant is discussed. Because of small conversions, a high-precision analysis for hydrogen by means of thermal conductivity cells was developed. An effect of reversible poisoning of the catalyst by water vapor was encountered. A discussion is presented of flow equations and precautions that must be used in their development. A mechanism for the hydrogenation reaction is proposed.

THIS paper records an experimental study and theoretical kinetic analysis of the catalytic hydrogenation of ethylene conducted under essentially isothermal conditions in a flow-type tubular reactor. A few experiments were performed also in which modest temperature gradients were permitted to develop. Because of their industrial importance flow-system reactions are of interest to the chemical engineer; because of the advantages of flow operation, this manner of conducting reactions is increasingly being utilized also by the student of theoretical chemistry. The present work was undertaken to study the specific variables of flow operation. Hydrogenation was chosen as the reaction vehicle because it is representative of an important industrial reaction step, because a considerable history of static kinetic studies is available and because it appeared to be, at least superficially, one of the less complicated reactions. Hydrogenation of ethylene is strongly exothermic and it has for this reason also been chosen for concurrent studies under way in this laboratory on heat transfer in catalytic reactors. The present paper therefore provides an isothermal kinetic background for quasi-isothermal design analyses of the type discussed in a previous paper by Wilhelm, Johnson, Wynkoop and Collier (*18*). Results of these design studies with the present reaction will be published at a later date.

The hydrogenation of ethylene has been studied by many investigators in the past forty years. Grassi (*4*), and others (*3, 5, 7-12,* and *16*), have studied the kinetics of the reaction over various types of reduced copper catalysts in static systems. The number of investigations of the hydrogenation of ethylene carried out on other catalysts, principally nickel, platinum, and palladium, is legion. Greenhalgh and Polanyi (*5*) have also studied the approximate rates of hydrogen exchange alone and during ethylene hydrogenation reaction over reduced copper catalysts. Taylor and Burns (*15*), and Pease (*8-9*) have made adsorption measurements of the reactants and product on reduced copper catalysts. Liang (*6*) has studied the adsorption of nitrogen on the unreduced and reduced catalyst used in the present work, and he has also measured the adsorption of hydrogen on the reduced mass. The investigation of the kinetics of this reaction carried out in a flow system with reduced copper has not been reported previously.

Development of Flow-System Kinetic Equations

The procedure in developing a rate equation for this work was to assume on the basis of recorded adsorption measurements the most probable types of adsorption equilibria for reactants and products on copper catalyst; the gases were to be taken one at a time. Rate equations assuming surface reaction controlling, and with surface concentrations in accord with the stated equilibria, were integrated for a flow reactor. The resulting equation was tested by means of experimental reaction measurements and conclusions were drawn regarding the tenability of the a priori assumptions. Experimental results permitted simplification of the assumptions regarding ethylene adsorption, and a revised, simplified kinetic equation was developed accordingly. The present section deals with the derivation of the original kinetic equation. The section on "Results" presents comparison with experiment. Readers who are interested primarily in the final kinetic expression are referred to Equations (34) and (35).

From measurements of adsorption by Taylor and Burns (*15*), and from measurements of adsorption and reaction rate on copper catalysts (*8-9*), it has been shown that active copper ad-

† Present address: Standard Oil Company (Ind.), Inc., Whiting, Ind.

sorbs ethylene in much greater amounts than hydrogen at room temperature. If it is assumed that possibly the sites which adsorb the hydrogen and ethylene are not of the same type, or at least non-competitive, and that the reaction is a bimolecular surface reaction involving adsorbed reactants one can proceed with the development of a kinetic equation which later will be subjected to experimental verification. The reaction is:

$$\underset{A}{H_2} + \underset{B}{C_2H_4} \rightarrow \underset{C}{C_2H_6} \qquad (1)$$

and the rate of the surface reaction may be written:

$$\frac{d(Ny_c)}{dV} = k'\theta_a\theta_b \qquad (2)$$

Where

N = moles/sec. of gas flowing in reactor at any point
V = volume of reactor in cc.
d = differential operator
θ = fraction of available catalyst surface covered
k' = specific reaction rate constant; g. moles/(sec.)(cc. of catalyst chamber)
y = mole fraction in gas phase

Subscripts

a refers to hydrogen
b refers to ethylene
c refers to ethane
i refers to inlet conditions of reactor
o refers to outlet conditions of reactor

Further, because of the relative adsorptions, one may try Langmuir isotherms of the following forms:

$$\theta_a = b_a y_a \pi \qquad (3)$$

$$\theta_b = \frac{b_b y_b \pi}{1 + b_b y_b \pi} \qquad (4)$$

Where

b = an adsorption equilibrium constant
π = total pressure in atmospheres

Thus Equation (2) becomes:

$$\frac{d(Ny_c)}{dV} = \frac{k'b_a y_a b_b y_b \pi^2}{1 + b_b y_b \pi} \qquad (5)$$

It is well to emphasize, before proceeding with integration, the assumptions which Equation (5) implies. These are:

a. Hydrogen and ethylene are adsorbed independently on the catalyst surface, or if not independently, only a small number of the sites available for adsorption are covered.
b. Hydrogen is not greatly adsorbed by the catalyst.
c. Ethylene is moderately adsorbed by the catalyst.
d. Adsorption of ethane is so minute as to be unimportant.
e. A Langmuir-type isotherm describes both the adsorption of hydrogen and ethylene.

With the additional restriction of no ethane in the feed gas, one can proceed to integrate Equation (5) isothermally in terms of y_a, the variable which is measured experimentally.

Referring to Equation (1) it follows that

$$N_a - N_b = y_{ai}N_i - y_{bi}N_i$$
$$= N_i(2y_{ai} - 1) \qquad (6)$$

and also

$$N_b + N_c = N_i y_{bi} = N_i(1 - y_{ai}) \qquad (7)$$

thus

$$\frac{N_a - N_b}{N_b + N_c} = \frac{2y_{ai} - 1}{1 - y_{ai}} \qquad (8)$$

Dividing through (8) by N the following is obtained:

$$\frac{N_a - N_b}{N_b + N_c} = \frac{y_a - y_b}{y_b + y_c} \qquad (9)$$

By definition

$$y_a + y_b + y_c = 1 \qquad (10)$$

From (8), (9) and (10) equations in y_a and y_b, y_a and y_c are:

$$y_b = \frac{y_{ai}y_a + 1 - 2y_{ai}}{1 - y_{ai}} \qquad (11)$$

$$y_c = \frac{y_{ai} - y_a}{1 - y_{ai}} \qquad (12)$$

A hydrogen balance across the reactor and the use of Equation (10) lead to:

$$N = \frac{N_i y_{ai}}{y_a + y_c} = \frac{N_i(1 - y_{ai})}{1 - y_a} \qquad (13)$$

Combine (12) and (13):

$$Ny_c = \frac{N_i(y_{ai} - y_a)}{1 - y_a} \qquad (14)$$

Equation (5) may be rearranged:

$$\frac{d(Ny_c)}{dV} = \frac{k'b_a}{\frac{1}{b_b\pi^2 y_a y_b} + \frac{1}{y_a\pi}} \qquad (15)$$

Make substitutions in (15) indicated by (11) and (14):

$$\frac{N_i}{dV}(y_{ai} - 1)\frac{dy_a}{(1 - y_a)^3} = \frac{k'b_a}{\frac{1 - y_{ai}}{b_b\pi^2 y_a(y_{ai}(y_a - 2) + 1)} + \frac{1}{y_a\pi}} \qquad (16)$$

Equation (16) may be split into two integrals, I and II. Solving I,

$$I = \frac{1}{-b_b\pi^2}\frac{N_i}{V}\int_{y_i}^{y_o}\frac{dy_a(1 - y_{ai})^2}{(1 - y_a)^2(1 - 2y_{ai} + y_{ai}y_a)y_a} \qquad (17)$$

Equation (17) is of the form:

$$I = -\frac{N_i}{V}\frac{(1 - y_{ai})^2}{b_b\pi^2}\int_{y_i}^{y_o}\left[\frac{A}{(a - by_a)} + \frac{B}{(a - by_a)} + \frac{C}{(e - fy_a)} + \frac{D}{y_a}\right]dy_a \qquad (18)$$

Solving by the procedure of rational fractions one obtains:

$$I = \frac{1}{b_b\pi^2}\frac{N_i}{V}\left[\frac{y_{ai} - y_{ao}}{1 - y_{ao}} + ln\frac{1 - y_{ao}}{1 - y_{ai}} + \frac{y_{ai}^2}{1 - 2y_{ai}}\,ln\,\frac{1 - 2y_{ai} + y_{ai}y_{ao}}{1 - 2y_{ai} + y_{ai}^2} - \frac{(1 - y_{ai})^2}{1 - 2y_{ai}}\,ln\,\frac{y_{ao}}{y_{ai}}\right] \qquad (19)$$

The following three substitutions are next made:

(a) Space velocity: $S = (N_i/V)$, moles feed/(sec.)(cc. catalyst) (20)

(b) $\Delta y = y_{ai} - y_{ao}$ (note that this is the reverse of a mathematical delta) (21)

(c) For small conversions that were anticipated experimentally in this work the logarithmic terms in Equation (19) have values close to 1.0 and the first term of the logarithmic expansions may be used, $ln\ u = u - 1$. The following simplified integral for I is thereupon obtained:

$$I = \frac{S\Delta y}{b_b\pi^2 y(1 - y)^2} \qquad (22)$$

Considering integral II (right-hand denominator of right side of Equation (16))

$$II = \frac{1}{\pi}\frac{N_i}{V}(1 - y_{ai})\int_{y_i}^{y_o}\frac{dy_a}{y_a(1 - y_a)^2} \qquad (23)$$

Integrating,

$$II = \frac{1}{\pi}\frac{N_i}{V}(1 - y_{ai})\left[\frac{y_{ai} - y_{ao}}{(1 - y_{ai})(1 - y_{ao})} + ln\frac{(1 - y_{ao})y_{ai}}{(1 - y_{ai})y_{ao}}\right] \qquad (24)$$

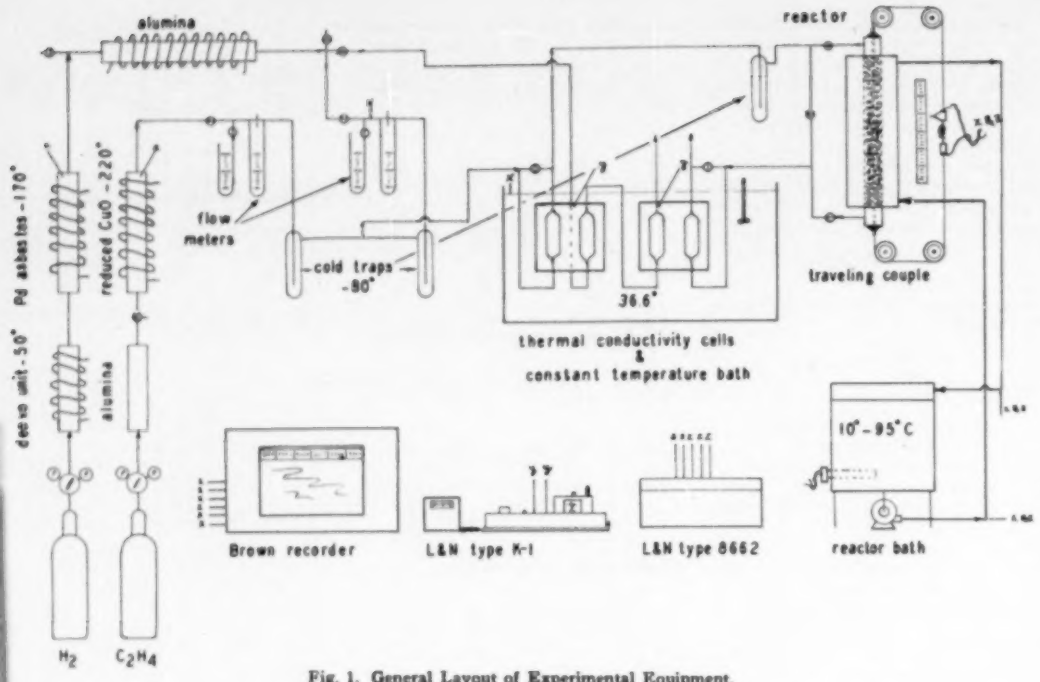

Fig. 1. General Layout of Experimental Equipment.

Equation (24) is an exact solution. Noting the definitions of (20) and (21) and the logarithmic approximation when applied to (24) the following is obtained:

$$II = \frac{S\Delta y}{\pi y(1-y)} \qquad (25)$$

Putting (25) and (22) together by means of (16), the final integrated expression is obtained in its approximate form for low conversions:

$$\frac{S\Delta y}{\pi y(1-y)} = \frac{-S\Delta y}{b_b\pi^2 y(1-y)^2} + k'b_a \qquad (26)$$

Equation (26), if the assumptions which underlie it are correct, should describe the isothermal kinetics of ethylene hydrogenation in a flow reactor with no ethane in the feed.

For a derivation of the general case of ethane originally present in the feed, the equations are considerably more difficult to develop. Their rational development depends upon procedures similar to Equations (1)-(26). The final exact solution is as follows:

$$k'b_a = \frac{1}{\pi l'}\left[\frac{y_{at}-y_{ao}}{(1-y_{at})(1-y_{ao})} + ln\,\frac{(1-y_{ao})y_{at}}{(1-y_{at})y_{ao}}\right] - \frac{S\Delta y}{b_b\pi^2(1-2y_{at}-y_{et})}\left[\frac{(1-2y_{at}-y_{et})+(1-y_{at})^2-(y_{at}+y_{et})^2}{1-y_{ao}} - \frac{(y_{at}+y_{et})^3}{(1-2y_{at}-y_{et})+(y_{at}+y_{et})y_{at}} + \frac{(1-y_{at})^2}{y_{at}}\right] \qquad (27)$$

For small conversions, i.e., when $y_{at} = y_{ao}$, Equation (27) reduces to:

$$\frac{S\Delta y}{\pi(1-y_{at})y_{at}} = \frac{-S\Delta y}{b_b\pi^2(1-y_{at})y_{at}y_{bt}} + k'b_a \qquad (28)$$

The choice of inlet concentrations as a basis in this equation is arbitrary, except for the term y_{bt}, but it serves to demonstrate that if $y_{at} = 0$ then $y_{bt} = (1-y_{at})$ and thus (28) degenerates to (26).

Experimental

Apparatus: The tubular reactor-and-jacket assembly and the general layout of experimental equipment are shown in Figure 1. The reactor, shown in detail in Figure 2, consisted of a ¼-in. Schedule 40 I. P. S. yellow brass tube, the wall of which had been turned down to one half its normal thickness. The tube was installed in a 1-in. I.P.S. brass jacket by means of brass end spacers which were silver soldered into place. Water was pumped at about 10 gal./min., and at constant temperature, through the jacket giving a water film coefficient of more than 1000 B.t.u./(hr.)(sq.ft.)(° F.).

Early reaction experiments with a prototype reactor which was provided with a tube wall thermocouple showed that with this water rate the tube wall and bath temperature were, for all practical purposes, identical. A 2-mm. O.D. hollow quartz tube was supported coaxially within the ¼-in. brass tube by means of suitable aligning supports. A butt-welded Number 32 iron-constantan thermocouple, drawn within the quartz tube was used to measure axial gradients within the catalyst bed which in turn was located in the annular space between reactor wall and quartz tube. By means of a rubber band, four polystyrene pulleys and a scale the thermocouple was centered within the quartz tube and was capable of axial travel and precise positioning within the reactor.

The reactor was supplied with hydrogen from a tank source. A purification train consisting of a Deoxo unit, platinized asbestos, alumina and a dry ice cold trap was provided. Tank ethylene was purified by means of alumina, freshly reduced copper oxide and a cold trap. Volumetric flow rates of both gases were measured with glass capillary flow meters. After mixing, the composition of the hydrogen-ethylene reaction gas was measured in calibrated thermal conductivity cells by comparison with the conductivity of hydrogen. Following reaction, the composition of the product gas was measured in another set of thermal conductivity cells. Although the product contained three components, conductivity measurements are possible because the conductivity of hydrogen differs greatly from that of ethylene and ethane, whereas the conductivity of the latter two gases is closely similar. The equivalent of a two-component system therefore results. Both sets of thermal conductivity cells were maintained at constant temperature in an oil bath.

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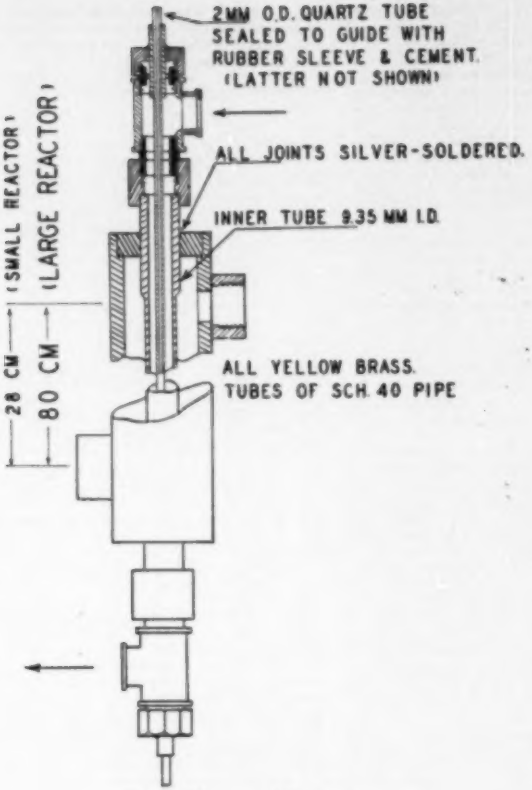

Fig. 2. Diagram of Reactors.

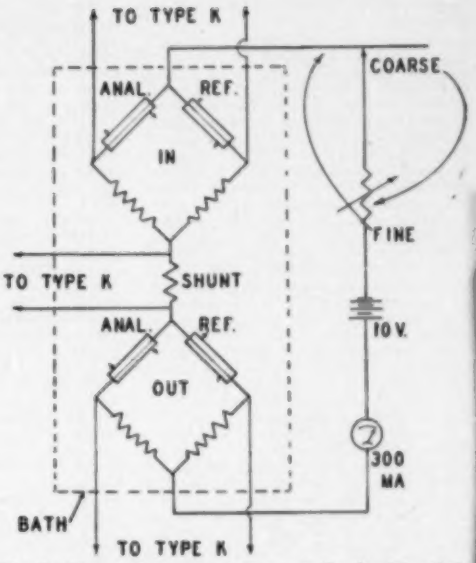

Fig. 3. Electrical Circuit of Thermal Conductivity Cells.

point instrument was used to record continuously temperatures in the thermal conductivity cell bath, in the reactor coolant line entrance and exit, in the axial reactor position, and at the gas flow meters. Final steady-state temperature readings for record purposes were measured on a Leeds and Northrup Type 8662 potentiometer. Voltage unbalance in the thermal conductivity analysis cells was measured with a Leeds and Northrup Type K-1 potentiometer.

Catalyst. The magnesia-copper catalyst was chosen because it has several favorable characteristics. It does not promote ethylene cracking at moderate temperatures, it is mechanically rugged, and it is easily made (*13, 14, 16*).

A single quantity of about 850 g. of the combined oxides was prepared for the entire study. Composition of the catalyst was prepared to be a 50 mole % mixture computed as copper and magnesium oxides. Nitric acid, magnesium nitrate and sodium hydroxide of C.P. quality were used in the preparation. Electrolytic copper reduced in hydrogen and reported to contain less than 0.0005% Ni was the source of the metal. The reverse precipitation technique of E. H. Taylor (*13, 14*) was employed. A dilute solution containing copper and magnesium nitrates was prepared and was dropped into a dilute, agitated sodium hydroxide solution during a period of 36 hr. The resulting hydroxides were washed with distilled water by decantation until a negative test for nitrate ion was obtained and filtered. The coprecipitated hydroxides were dried, ball milled and calcined to convert them to oxides. The final, active catalyst was prepared by reduction in place by hydrogen. For further details reference may be made to the dissertation (*20*) upon which this paper is based.

Catalyst was prepared for use in the reactor by making a heavy paste of the oxides and placing this material between the sheets of quantitative filter paper. The resulting sandwich was pressed in a cold hydraulic press to form a hard, dense sheet about 0.06 in. in thickness. Approximate cubes were cut from the sheet with a razor blade and the particles were air dried, screened and stored. Since more than sufficient water was added to the catalyst to hydrate the magnesia, the procedure led to uniform catalyst composition.

X-ray diffraction patterns were prepared and the arc spectrum was examined under the guidance of Dr. J. Turkevich of the chemistry department of Princeton University. No trace of nickel was found. The surface area of the catalyst was measured kindly by S. C. Liang (*6*) and was found to be 80 sq.m. (on the reduced catalyst) per gram of dried, *unreduced* catalyst. The area of the unreduced catalyst on this same basis was about one-half of this value. The surface was measured with nitrogen and the molecular spacing was assumed that of liquid nitrogen. The dead space was measured with helium.

Reactant Gases. A few problems deserve to be mentioned that were encountered in the preparation of gases with sufficient purity to permit the prime reaction to run for extended periods. It was found, for example, that the source of tank hydrogen may have a bearing upon the efficiency of the purification train. Hydrogen from the Linde Air Products Co. was used. Early in the work short lengths of Tygon tubing were used as connectors, but it was found that water vapor from air will diffuse through this material, particularly under high humidity conditions, to affect seriously the thermal conductivity analysis of the reaction gases. In the final apparatus all connections were made of glass or flexible bronze tubing.

The small quantities of oxygen in tank hydrogen were converted to water vapor over palladium in Deoxo units of the Baker Platinum Co. The resulting wet hydrogen was dried in a column of granular activated alumnia approximately 4 ft. long and 2½ in. in diameter. The glass alumina column was wound with a heating coil to permit reactivation in place with tank hydrogen flowing through it. This procedure avoided oxygen contamniation from the dehydration column and permitted a high degree of dehydration of the alumina during reactivation even during the humid summer months when the ordinary oven-drying of alumina is profoundly affected by the ambient humidity.

Cylinder ethylene was obtained from U. S. Industrial Chemicals Co. Trace quantities of oxygen were removed by direct re-

action with about 200 g. of freshly reduced copper oxide in the form of copper oxide wire fragments. Reductions were carried out on a cycle time dictated by the oxygen content of the ethylene. An alumina column was used also to dry the ethylene gas after oxygen removal.

Carbon dioxide cold traps in each gas line following the respective capillary flow meters were final safety devices used to remove water vapor and to insure the substantial absence of dibutyl phthalate manometer fluid from the gas streams either by vaporization or gross spillage. During proper operation, the cold traps accumulated no material.

Gas Analysis. Leeds and Northrup thermal gas conductivity cells were used to measure the compositions of the hydrogen-ethylene reactant and hydrogen-ethylene-ethane product mixtures. Considerable investigation and refinement in technique beyond that heretofore reported in the use of these cells was necessary until an adequate stability and precision was achieved. In the hydrogenation of ethylene, if substantially isothermal conditions are to be maintained, the large heat of reaction requires that conversion levels be maintained at one-half per cent hydrogen reacted, or less. To obtain an analytical precision of measurement of, say less than ±10% at this conversion level the analysis must be capable of detecting a hydrogen change of ±0.05%. To obtain such precision, or better, it was necessary to consider the effect of cell current, cell temperature, absolute gas pressure in the cells, gas flow rate through the cells, and the method of calibration.

The electrical arrangement is shown in Figure 3. Each unit consists of a hydrogen reference cell and a measuring cell. It was found that a cell current precise to about 2 parts in 10,000 was required. This was attained at a cell current of 300 ma. through the use of a shunt electrically connected between the two cells. The shunt was immersed in the cell constant temperature bath and the voltage drop across it was measured with a Type *K*-1 potentiometer. The voltage drop across the shunt was set at an arbitrary value to ±0.002 mv.

The conductivity cells are sensitive to temperature and distribution of temperature or degree of agitation. In the final arrangement of several studied the cells were placed in a Mentor No. 28 oil bath which was propeller agitated. A thermal lag between the interior of the cell-housing and the bath was minimized by replacing the original bakelite cover with aluminum cover plates. The bath temperature was controlled to within ±0.02° C.

The effect of total static gas pressure upon the measuring cell system between 760 and 950 mm. Hg. was found to be negligibly small. The cells also were found to be free of effects due to total gas flow rate at rates less than 40 cc./sec. By means of a by-pass it was arranged to flow no more than this gas rate through the cells. Exit streams from the hydrogen reference cells were sealed from the air of the room by means of dibutyl phthalate bubblers. Prime gas streams were vented outside the building.

When it was established that the just-mentioned perturbing influences had been minimized, cell calibrations were performed. Known gaseous mixtures were prepared by mixing known flows of hydrogen and ethylene. The individual gas flows were measured with capillary flow meters previously calibrated with a statically calibrated precision wet test meter. Corrections for temperature and absolute pressure changes on the capillary flow meters were made by the method of Whitwell (*17*). Equations for the capillary flow meters were fitted by means of the method of least squares and calculations showed the possible error due to the flow meters to be ±2.8% at a 2σ limit.

In examining the characteristics of the Leeds and Northrup thermal conductivity cells it had been found in the previous studies of Collier (*2*) that ethane was not differentiated from ethylene as long as the hydrogen concentration was kept above 35%. Further it was noted in the present work that from 35% to 100% hydrogen the following equation might be used to represent the calibration curve:

$$\text{Cell millivolts} = A \log_{10}(H\%) + B \qquad (29)$$

where A and B are constants.

Now while the error involved in the use of the capillary flow meters was about 1%, a much higher degree of precision was obtained in the calibration of cells with the flow meters by fitting through the use of least squares a large amount of calibration data to Equation (*29*). For example, the equation for cell No. 510,199 was

$$\text{mv.} = -278.614474 \log_{10}(H\%) + 557.562484 \qquad (30)$$

The large number of significant figures is required because of subtraction of large numbers involved.

The precision in hydrogen measurement for electrical reasons only is obtained by differentiating (*29*) or (*30*). Thus

$$d(\text{mv.}) = \frac{-278}{2.3}\left(\frac{d(H\%)}{H\%}\right) \qquad (31)$$

For an error in potential reading of 0.002 mv.

$$100\left(\frac{dH\%}{H\%}\right) = \pm 0.003\% \qquad (32)$$

Thus at 100% hydrogen concentration the absolute error is ±0.003% and at 35% hydrogen, ±0.0011%.

Small residual differences in cell characteristics were noted and corrected for after determining the difference in each experiment. Reactant gases were passed around the reactor and were sent through the reactant and product cells simultaneously to establish the difference. The net error from all sources in the computed ethylene conversion percentage (absolute) is estimated to be no greater than 0.006%.

Table 1 Preliminary Kinetic Series OO and O

Copper-Magnesia catalyst essentially cubic, screened through #8 (.0937") onto #12 (.0661") standard screen. D_p = 0.1102". Bulk density not measured.

Feed Rate mols/sec. x 10^3	Space Velocity, S total mols/sec.cc. x 10^4	Y_{ao}	Δy	Temperatures Wall	Bed in	Bed out	$1/T_{av}$ x10^3	$S\Delta y/Y_{ao}(1-Y_{ao})$ x 10^7	$S\Delta y/Y_{ao}(1-Y_{ao})^2$ x 10^7	Cumulative Time on Stream
Series C Catalyst volume 0.74 cc.										
1.375	18.60	.39584	.00126	70	70	82.5	2.87	254.	621.	
1.375	18.60	.39580	.00100	70	70	82.5	2.87	234.	590.	
2.23	30.20	.51365	.00202	70	70	75	2.90	244.	562.	
0.88	11.9	.59299	.00317	59.5	59.5	71.5	2.96	180.	409.	
.814	11.0	.58862	.00114	49.5	49.5	52.0	3.09	93.	2.14	101.5 hrs.
Series OO Catalyst volume 5.34 cc.										
.423	.794	.394	.00746	45	45	90	3.12	24.7	41.	11.5 hrs.
.534	1.00	.4420	.00621	45	45	90	3.12	25.2	45.5	
.730	1.368	.47072	.00469	45	45	90	3.12	24.6	47.6	
1.032	1.920	.54691	.00329	45	45	49	3.12	25.0	56.6	
1.26	2.36	.57999	.00273	45	45	48.7	3.13	25.0	63.4	
2.265	4.25	.60567	.00113	45	45	48	3.13	20.2	51.5	19 hrs.
.309	.580	.36009	.00942	45	45	49.5	3.12	23.6	37.2	
.272	.509	.32035	.00824	45	45	49.5	3.12	19.0	28.3	
2.205	4.14	.59448	.00142	45	45	47.7	3.13	24.4	60.6	
.983	1.84	.54619	.00308	45	45	47.7	3.13	22.8	50.5	
.689	1.29	.47940	.00323	45	45	49.5	3.12	26.15	131. •	
.740	1.389	.72818	.00352	45	45	90	3.12	24.8	91.9	
.655	1.225	.70010	.00408	45	45	90	3.12	23.8	79.5	
.935	1.190	.68035	.00385	45	45	49.6	3.12	21.1	66.4	20.5 hrs.
.740	1.381	.69012	.00178	45	45	49	3.12	26.9	204.	
.804	1.502	.46196	.00400	45	45	50	3.12	24.2	65.	
.980	1.85	.54758	.00337	45	45	50.1	3.12	25.2	55.8	41.5 hrs.
.568	1.064	.48614	.01629	55	55	69	2.99	69.4	110.	
1.27	2.48	.79536	.00470	55	55	67.5	2.99	68.5	340.	
1.05	1.982	.74210	.00752	55	55	70.1	2.99	74.	515.	
1.075	1.962	.75139	.00580	55	55	70.5	3.00	79.	519.	
1.486	2.79	.78850	.00580	55	55	69.8	3.01	67.5	212.	
1.940	3.64	.80760	.....	55	55	65	3.00	70.0	758.	
1.02 •	1.91	.77040	.00616	55.1	55.1	68	2.97	67.	292.	
• Catalyst intentionally oxidized and re-reduced at end of this run to check reproducibility.										
1.02	1.91	.76977	.00606	55	55	68	2.99	65.6	285.	
1.01	1.892	.77300	.00267	45	45	50	3.12	28.8	126.9	
.363	.68	.78746	.00189	27.8	27.8	29.1	3.12	7.00	30.	
.296	.555	.73054	.00249	27.8	27.8	29.1	3.12	8.4	31.6	

Operational Techniques. The catalyst bed was filled with a generous support bed of granular celite, then with the desired amount of catalyst, and finally with a preheating section of granular celite. The reactor assembly was heated by means of hot air passed through the jacket and catalyst reduction in a stream of hydrogen was carried out at 250° C. until water vapor evolution had substantially ceased. For a small charge of catalyst, reduction required about four hours.

After reduction, water lines were attached to the jacket and the reactor temperature was adjusted for the procedures by which the catalyst was brought to uniform and reproducible activity. The catalyst was subjected to a sudden switch from hydrogen to an ethylene rich gas and then, over the period of many hours operation was continued until temperatures and conversions reached plateau values. This plateau activity was found to remain satisfactorily constant for the catalyst at all permissible temperatures and concentrations for hundreds of hours, provided the reactants remained free of oxygen and water vapor. Oxidation and re-reduction when performed less than about seven times did not appear to alter the activity of the catalyst. There is evidence that many prolonged and repeated oxidation and reduction cycles may increase the catalyst activity slightly. This observation is in accord with industrial experience with rugged catalysts.

Kinetic experiments were arranged experimentally to have catalyst temperature increases above the wall as low as possible, generally 3-5° C. or less. Linear average temperatures over the catalyst bed were used for the isothermal values used in checking Equation (*26*). Catalyst volumes and conversions also were kept small intentionally because of the approximations in deriving this equation.

Catalyst temperature, hydrogen and ethylene flow rates and jacket temperatures were controlled in a given experiment and the inlet and outlet hydrogen concentrations were measured. Differential and static pressures and the temperature were taken at the flow meters and the barometric pressure was recorded. When catalyst temperatures were excessive, four things could be done to bring them into the desirable range. Increase in total flow rate was noted to lower catalyst temperatures. Decrease in hydrogen percentage had the same effect. Reduction of reactor jacket temperature also reduced the rate of reaction and thus the catalyst temperature spread. As a last resort, if certain desired concentrations and flow rates could not be reached at a particular jacket temperature, the amount of catalyst in the bed could be reduced.

Additional details of catalyst reduction and operational procedure are available (*20*).

Results

Experimental. To provide data for kinetic analysis, isothermal rate studies were performed. Experimental variables and their limits were as follows:

Hydrogen concentration	32.6-95.2%
Temperature	9-79° C.
Space velocity	0.20-32.0 × 10^{-4} total moles/(cc.)(sec.)
Catalyst particle size	0.108 to 0.279 cm. equivalent sphere diameter

Absence of an effect of mass transfer on the measured kinetics was established by computation and comparison with experimental rates. The effect of water vapor poisoning of the catalyst was noted.

Data and computed results are presented in Tables 1 and 2. In Table 1 the results of two sets of preliminary runs, Series 00 and Series 0, are given. These runs differ primarily from later, final kinetic runs in that the catalyst was charged by volume and catalyst weight was not recorded. In the final kinetic runs both these quantities were measured.

Series 00 was performed with cubical catalyst particles, 8- to 12-mesh screen size, with screen average particle diameter of 0.080 and with an equivalent sphere diameter of 0.110 in. based upon equal surface areas. The majority of the runs were performed at 47° C. and were used initially to test the validity of the derived kinetic equations, to check upon the permanence of catalyst activity over an extended period of operation (100 hr.) including runaway reactions, deliberate oxidations and re-reductions and reaction temperature cycling.

Series 0 experiments were performed with catalyst previously used in Series 00. Series 0 differs from Series 00 in that a source of moisture in the system was removed between them. Before starting the Series 0 runs it had been noted that a faint film of moisture had collected near the cool exit of the copper scavenging furnace, and while it was customary to back-flush and reactivate this furnace carefully with hydrogen daily, it seemed desirable to install an alumina adsorption column after the copper furnace, although it was difficult to see at the time how water vapor could find its way through the copper furnace and cold trap which followed the flow meters. Subsequently it was proved that the moisture had come through a Tygon connection used in the system, and when the Tygon was replaced with a glass seal the alumina column was removed.

Kinetic runs of Series 1, 2, 3*A* and 3*B* were made with 12- to 16-mesh, cubical catalyst with a standard mesh size between No. 12 and No. 16. The average mesh diameter was 0.056 in. and the equivalent spherical diameter, 0.78 in. Repeated packing in a dummy tube gave an average bulk density of 0.783 g./cc. ±4%. The bulk density of the larger catalyst of Series 00 and 0 also was a value within these limits. The use of mercury in a special pyenometer led to a particle density of 1.300 g./cc. which permitted computation of interparticle voids in the reactor of 39.8%.

Series 1 experiments cover a range of space velocities, and temperatures between 52 and 72° C. At the end of this series a slight hot spot began to develop near the bed entrance. Prior to proceeding with a low temperature run at 12° C. the catalyst was aged for an additional 20 hr. at 10° C. The subsequent runs at 10-12° C. constitute Series 2.

In the experiments of Series 3*A* water vapor was present in the reaction system. Series 3*B* are the results when the alumina column had been regenerated to remove the source of the vapor.

Series 4 experiments were performed to determine the effect, if any, of catalyst particle size upon the effectiveness of the catalyst. Mesh size was No. 16-No. 18, average mesh diameter, 0.043 in. and equivalent sphere diameter, 0.059 in. Bulk density was 0.845 g./cc.

The sole experiment of Series 5 was performed to obtain additional evidence with regard to the effect of water vapor on catalyst activity. In this experiment water vapor was purposely introduced with a low partial pressure by means of ice water at 0° C. in the cold trap of the hydrogen line.

Kinetics. Equation (*26*) suggested that if the abscissa,

$$\frac{S\Delta y}{\pi^2 y(1-y)^2}$$

and the ordinate,

$$\frac{S\Delta y}{\pi(1-y)y}$$

be plotted from experimental data, a straight line should result with a slope of $-1/b_b$ and an intercept with the value of kb_a. Complete results of Series 00 are presented in this manner in Figure 4. It is noted that the slope effectively is zero. For convenience, the data are compressed by the use of logarithmic coordinates. Zero slope indicates that b_b, the ethylene adsorption equilibrium constant is large and the assumption in Equation (5) that ethylene is moderately adsorbed must be modified to strong ethylene adsorption, i.e.,

$$\theta_b = 1 \qquad (33)$$

Equation (33) is therefore substituted in Equation (*2*) and the basic differential equation reduces to:

$$\frac{d(Ny_e)}{dV} = k'b_a y_e \pi \qquad (34)$$

which means that the reaction is overall first order with respect to hydrogen alone. The reaction is pseudo first order with respect to hydrogen because of the large excess of ethylene molecules at the reaction sites. Making the substitution of (14) into (34), separat-

Table 2

Kinetic Series 1, 2A, 2B, 3, 4, 5

Feed Rate mols/sec. x 10^5	Space Velocity mols/sec. cc. x 10^4	y_{ao}	Δy	Temperatures Wall	Bed in	Bed out	$1/T_{av}$ x 10^3	$\frac{S\Delta y}{y_{ao}(1-y_{ao})}$ x 10^7	$\frac{S\Delta y}{y_{ao}(1-y_{ao})^2}$ x 10^7
Cubic Catalyst screened through #12 (.0661") onto a #16 (.046") standard screen. Dp calculated to be 0.078". Bulk density is 0.781 gm./cc. ± 4%.							Catalyst weight 0.52 gms.; volume 0.664 cc.		
Series 1.									
1.41	21.3	.38587	.00312	72	72	82	2.86	281	456
1.41	"	.38408	.00320	72	72	82	2.86	288	467
1.41	"	.38573	.00165	61.5	61.5	65.5	2.98	148.5	242
1.41	"	.38640	.00079	52.5	52.5	54.1	3.06	71.0	115.8
1.41	"	.38604	.00074	52.5	52.5	54.1	3.06	66.5	108.2
1.72	26.0	.54092	.00233	71.5	73.5	81.8	2.85	244.	532.
1.72	"	.53921	.00229	71.5	73.5	81.8	2.85	240.	520.
1.72	"	.53923	.00121	71.5	73.5	81.8	2.97	126.5	275.
1.72	"	.53952	.00069	51.7	51.7	54.1	3.07	72.3	152.
1.72	"	.53945	.00067	51.7	51.7	54.1	3.07	70.4	153.
2.11	31.9	.63623	.00174	72.3	73	82.1	2.85	240.	659.
2.11	"	.63875	.00103	60.6	60.5	65.0	2.98	142.	395.
2.11	"	.64066	.00050	52.5	52.5	55.0	3.06	69.1	193.
2.11	"	.64023	.00049	52.5	52.5	55.0	3.06	67.8	189.
1.885	28.4	.84456	.00140	72	72	87	2.84	303.	1950.
1.885	"	.84394	.00142	72	72	87	2.84	306.	1970.
0.91	14.0	.39761	.00224	61	61	66.9	2.97	131.	218.
0.91	"	.39759	.00234	61	61	66.9	2.97	136.9	227.
.538	8.12	.43631	.00212	52.5	52.5	56.5	3.06	70.	124.2
Series 2.									
							3.54	2.57	4.40
							3.54	1.99	4.74
.556	.436	.41540	.00143	10	10	10	3.50	4.11	10.55
.755	.591	.51053	.00082	10	10	10	3.50	3.79	15.22
.260	.204	.75119	.00378	12	12	12.7	3.50	3.84	26.3
.260	.204	.75080	.00348	12	12	12.7	3.50	3.90	27.1
.42	.329	.85393	.00145	12	12	12.7	3.50	3.88	49.8
.42	.329	.85621	.00146	12	12	12.7	3.50	3.74	48
.685	.536	.92146	.00052	12	12	12.7			
.685	.536	.92169	.00050	12	12	12.7	Catalyst weight 4.6 gms.; volume 5.10 cc.		
Series 3A.									
.481	.945	.38089	.00164	37.5	37.5	41.0	3.20	14.65	23.2
.469	.919	.426015	.00424	36.5	36.5	40.0	3.21	15.9	27.8
.358	.703	.54115	.00917	47	47	51.8	3.10	26.0	56.7
Series 3B.									
.266	.521	.40484	.0148	36.5	36.5	44.0	3.19	32.2	54.1
.266	.521	.40113	.0151	36.5	36.5	44.0	3.19	32.7	54.6
.362	.710	.51067	.00945	36.5	36.5	44	3.19	28.3	72.5
.362	.710	.51103	.00952	36.5	36.5	44	3.19	28.4	73.2
.698	1.370	.77568	.00349	37.5	37.5	42	3.20	27.7	124.
.564	1.109	.90804	.00240	37.6	37.6	42.8	3.195	31.8	340.
.766	1.50	.93294	.00134	37.7	37.7	42.8	3.19	32.3	481.
.766	1.50	.93256	.00136	37.7	37.7	42.8	3.19	32.6	485.
1.062	2.09	.95126	.00069	37.6	37.6	42.2	3.195	31.2	640.
1.062	2.09	.95113	.00070	37.6	37.6	42.2	3.195	31.4	640.
.360	.708	.60340	.01034	37.1	37.1	42.4	3.195	30.7	77.
Cubic Catalyst screened through #16 (.046") onto a #18 (.0427) standard screen. Dp = 0.059". Bulk density is 0.845 gm/cc.							Catalyst weight 2.70 gms.; volume 3.18 cc.		
Series 4.									
.710	2.29	.75973	.00404	42.5	42.5	49	3.14	50.9	212.
.710	2.29	.76157	.00195	35	35	38	3.23	24.6	103.
Series 5.									
.477	1.495	.89527	.00156	50	50	52	3.10	24.8	236.

ing variables and integrating, Equation (35) is obtained:

$$k'' = k'b_a = \frac{S\Delta y}{wy_{ao}(1-y_{ao})} \quad (35)$$

This is the final rate equation. It is indicated that the proper hydrogen concentration to use is the exit concentration.

Data of kinetic experiments of Series 1, 2, and 3*B* are also plotted in Figure 5 in accord with Equation (26), furnishing additional verification that the reaction is first order with respect to hydrogen. This figure includes data in the temperature range from 13 to 79° C., space velocity from 0.21×10^{-4} to 31.9×10^{-4} moles/(sec.)(cc.), hydrogen concentration from 38 to 95%.

Effect of Temperature. The apparent energy of activation for the reaction was obtained from the Arrhenius equation, illustrated in Figure 6 by the logarithm of the rate constant from Equation (35) versus reciprocal absolute temperature. All points of Series 0, 1, 2, 3*B* and 4 are included. The following equation represents a least square fit of the data:

$$k'' = k'b = Ae^{-E/RT}$$
$$= 5960e^{-13,320/RT} \quad (36)$$

The energy of activation is 13.3 k.cal./g.mole and the data fall within a 10% error band about the least square line.

The apparent energy of activation of preliminary series 00, in which moisture was present, was 13.2 k.cal./g. mole which agrees within experimental error with the above result for the final kinetic data.

Effect of Mass Transfer. Early in this investigation the question arose whether mass-transfer rates are important. A comparison of typical measured hydrogenation rates with diffusion rates computed from the correlations of Wilke and Hougen (*19*) showed that in no case do the reaction rates approach within 1/1000th of the mass-transfer rates. The measured rates may therefore be taken to represent completely the surface reaction mechanisms.

Effect of Catalyst Particle Size. Rate constants were determined with three

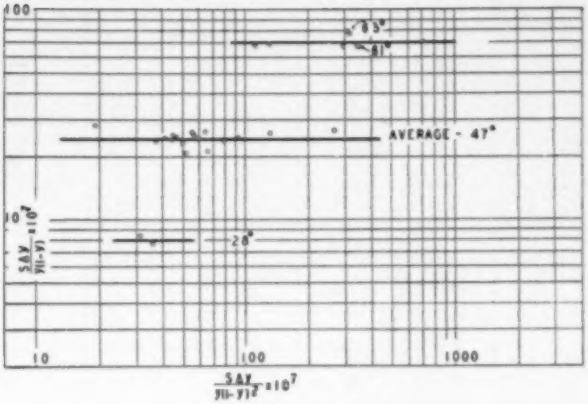

Fig. 4. Data of Preliminary Series 00 Experiments Plotted According to Equation 26.

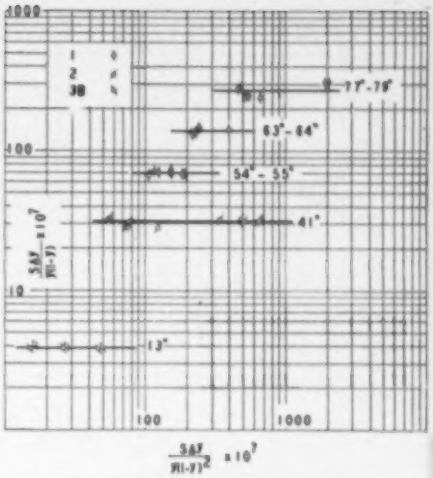

Fig. 5. Data of Final Kinetic Runs Plotted According to Equation 26.

particle sizes of catalyst, 0.059 in. for Series 4, 0.078 in. for Series 1, 2 and 3, and 0.110 in. for Series 0. All are represented in Figure 6. No observable difference in effectiveness between catalyst of different particle sizes is noted.

Water-Vapor Poisoning. It was found in exploratory operation that high concentrations of water vapor, of the order of 20 mm. destroy the catalyst activity completely. This effect had also been observed by Collier (*2*) in this laboratory. However, when small partial pressures of water vapor were inadvertently introduced into the system the catalyst activity was decreased to about one-half its normal value with a dry system and the energy of activation remained constant. The behavior was reversible because, on removal of the water source, the normal high activity was slowly recovered without the necessity of regeneration of the copper-magnesia catalyst. This occurred in preliminary Series 00 in which water vapor diffused into the system through Tygon tubing. Upon removal of the Tygon the higher activity, experienced in all dry runs was achieved and the results are listed in Series 0. Likewise, in Series *3A* it was discovered after a few runs that the activity was at the lower level. The alumina drying tube was known to be near the end of its operating cycle and it was presumed that traces of water vapor were escaping. Upon reactivation of the alumina and resumption of ethylene reduction in runs designated as Series *3B*, the normal, higher activity was again obtained and the assumption with regard to water vapor in *3A* was presumed correct.

An Arrhenius plot for the temperature variation of the over-all rate constant for the water-poisoned experiments of Series 00 and *3A* are presented in Figure 7. The equation is:

$$k'' = Ae^{-E/RT} = 3500e^{-13,320/RT} \qquad (37)$$

The energy of activation for the poisoned runs was the same as that for unpoisoned experiments. The entropy term, A, however is seen to be 3500 which is considerably lower than 5960 for the unpoisoned run. It is noteworthy that the data of water-poisoned experiments should so closely describe a single activity level in Figure 7 although undoubtedly the water vapor partial pressure varied widely within the low concentration range.

Although the study of water-vapor poisoning was foreign to the main purpose of the present work it was desirable to perform an experiment with a conscious introduction of water vapor. The comparison is presented in Series 4 and 5. The two experiments of Series 4 were entirely normal and were found to be properly described by Equation 36. Water vapor was then introduced by placing a small quantity of water at 0° C. in the hydrogen line cold trap jacketed at 0° C. The gas did not bubble through the liquid water but swept over the surface. The vapor pressure of water was therefore probably considerably less than 4.6 mm. Hg. The resultant hydrogenation rate measurement, given as Series 5, showed an immediate decrease in activity compared with Series 4. An examination of Figure 7 shows that the Series 5 point with added water is consistent with previous experiments which had been presumed poisoned by the presence of water vapor.

Precision of Results. Errors in the determination of the rate constant may arise from errors in the determination of the measured variables in Equation (35) and also from errors in the measurement of temperature with an effect through the Arrhenius equation. Each of these sources of error will be considered separately.

Equation (35) may be rewritten in terms of directly measured quantities as follows:

$$k'b_s = k'' = \frac{S\Delta y}{\pi y_{a0}(1-y_{a0})} = \frac{N_t}{V}\frac{\Delta y}{y_{a0}(1-y_{a0})\pi} \qquad (38)$$

Taking logarithms of the terms in (38)

$$ln\ k'' = ln\ N_t - ln\ V + ln\ \Delta y - ln\ y - ln(1-y) \qquad (39)$$

and differentiating:

$$\frac{dk''}{k''} = \frac{dN_t}{N_t} - \frac{dV}{V} + \frac{d\Delta y}{\Delta y} - \frac{dy}{y} + \frac{dy}{(1-y)} \qquad (40)$$

The approximate errors in determination of these individual quantities are:

Flow Rate, N_t	= ±3%
Catalyst Volume, V	= ±4%
Conversion, Δy	= ±6%

The errors involved in the determination of y and $(1-y)$ in the middle concentration range are mutually compensating and are therefore not further considered. The maximum error because

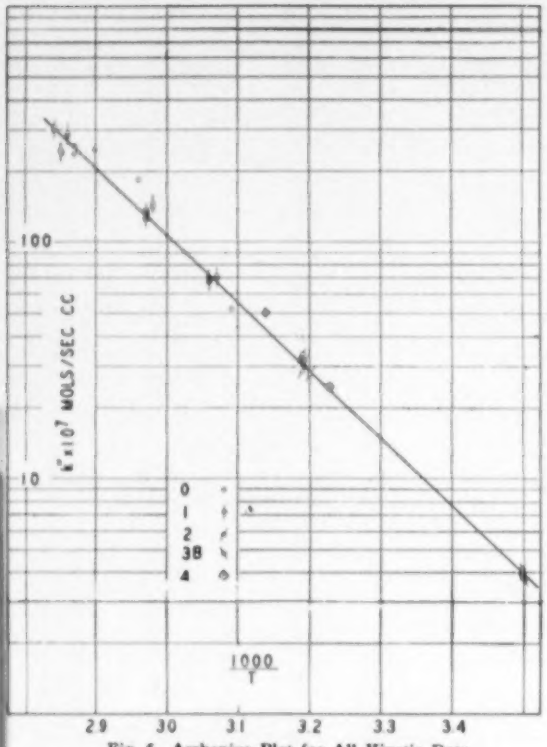

Fig. 6. Arrhenius Plot for All Kinetic Data.

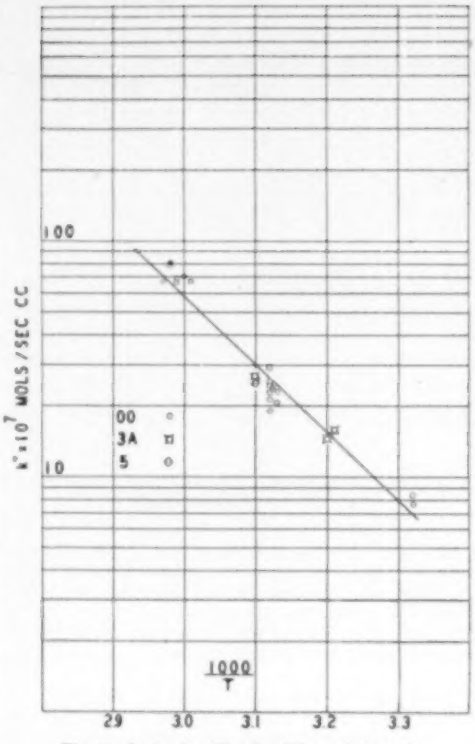

Fig. 7. Arrhenius Plot for Water-Poisoned Experiments.

of the variables listed above, therefore, is:

$$\frac{dk''}{k''} = \pm .03 + .04 + .06$$

$$+ \pm 0.13 = \pm 13\% \qquad (41)$$

This means that all kinetic runs should agree within about ±13% and that within any series of runs, the agreement should be (volume error missing) about ±10%. Data in Figure 6 are within these ranges.

In considering the effect of temperature measurement upon the reliability of k'', reference to Equation (36) will recall that the over-all rate constant is an exponential function of temperature. An arithmetic average of inlet and outlet bed temperatures was used as an effective temperature in computing the data which Equation (36) represents. This equation should therefore be analyzed for the magnitude of error possibly produced in k''. Differentiating Equation (36):

$$\frac{dk''}{k''} = \frac{13.320}{RT}\left(\frac{dT}{T}\right) \qquad (42)$$

Assuming an error of 1° C. is involved in substituting an average temperature into the isothermal equations, Equation (43) is obtained at 308° K:

$$\frac{dk''}{k''} = 7\% \qquad (43)$$

It is entirely possible that between errors resulting from conversion, flow rate and temperature within any one run the precision in k'' may be ±17% and between all runs, under adverse conditions ±20% when the error in measuring catalyst volume is included. If Equation (36) is redifferentiated for error in E with constant k'' and variable temperature, it will be found that E can be obtained with extreme precision provided a large number of experimental points with small temperature gradients within a run are available.

The section above should serve to indicate the need for high precision in catalytic investigations. Certain variables, temperature for example, often place restrictions upon the degree of conversion which may be obtained, and as a consequence analytical methods of considerable refinement are necessary. Data in which large temperature gradients and inexact analysis are reported must be examined critically when conclusions regarding mechanisms are based upon them.

Non-Isothermal Experiments. Non-isothermal experiments were performed in a longer reactor than was used in the isothermal run but with equal diameter. Dimensions of both reactors are given in Figure 2.

The experimental determination of the axial temperature profiles and over-all conversions were carried out with the same batch of No. 12-No. 16 standard mesh size catalyst as had been used in the kinetic experiments. The catalyst occupied 50 cm. of length, was supported on a 20-cm. section of celite of the same grain size, and was preceded by a 20-cm. preheating section of the same celite. A similar operating technique was used as in the kinetic experiments with the exception that the larger bed of catalyst required a longer activation time, of the order of 24 to 36 hr.

Experiments were performed with a 50 mole % mixture of hydrogen and ethylene and at flow rates of 6.25, 12.5 and 25.0 standard cc. of reactant mixture/sec. Wall temperatures, with one exception, were limited to a maximum of 35° C. because of the high activity of

the catalyst. The experimental conditions for the different runs are noted in Figures 8 and 9 in which axial profile temperatures relative to the wall are plotted against axial positions. Twenty minutes of operation were ample to allow the temperature distribution within the bed to become stabilized.

Typical profiles with temperature maxima are shown. It is interesting to note the reproducibility of such data. Runs 2 and 7 are duplicate experiments although five other experiments were performed between them. Temperatures of Experiment 11 were measured as the wall temperature was raised to just short of run-away conditions. It may be noted that inhomogeneities in catalyst reactivity are amplified, although at lower temperatures these do not seem to be important because of the conditioning treatment given.

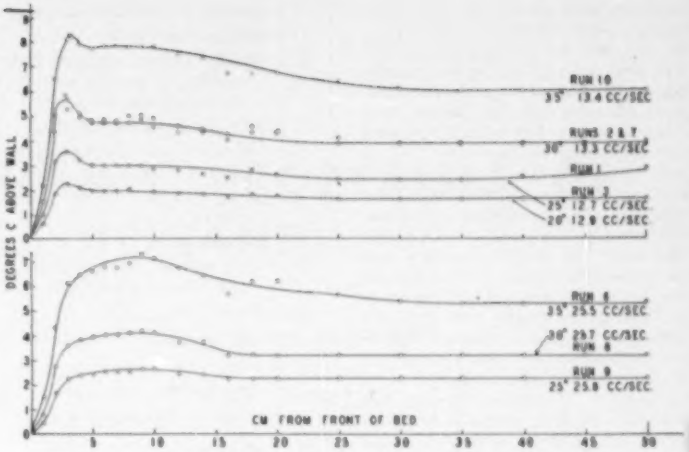

Fig. 8. Axial Temperature Profiles in Non-Isothermal Experiments.

Comment on Results

A previous derivation by Benton (*1*) for different flow reactions, when applied to small conversions in the hydrogenation of ethylene and employing the nomenclature of the present paper, leads to the following equation:

$$k'b_a = \frac{S\Delta y}{wy} \qquad (44)$$

This equation does not correlate the data of the present study as a widespread variation of the rate constant is evident. It differs from Equation (35) by the term $(1-y)$. An averaging procedure was used by Benton which led to the assumption of constant N for purposes of integration. This may be nearly so, but not actually, as shown by the following equation:

$$d(Ny_c) = Ndy_a + y_c dN \qquad (45)$$

The contribution of the change in the total number of moles of gas flowing through $y_c dN$ may form an appreciable percentage of the total variation, $d(Ny)_c$, and may not be neglected in the hydrogenation of ethylene even though the conversion is small.

Several writers have suggested that unintegrated forms, or averaged forms of unintegrated expressions may be used to analyze rate data. Opportunities for error exist unless the method is similar, say, to that of Pease (*8*), in which a graphical differentiation of integral rate data is performed and the result of this used in the differential equation. Particular care must be exercised in the analysis of rate data from a differential reactor in an unintegrated expression for a reaction in which there is a volume change. Both terms in Equation (45) must be used unless it is established that ydN is small compared with Ndy.

As mentioned in the introductory section of this paper, the kinetics of the hydrogenation of ethylene in static systems over various types of reduced copper catalysts has been studied by a number of investigators and in general the reaction was found to be first order with respect to hydrogen although in some cases, a dependence upon the ethylene concentration also was reported. It is particularly interesting to compare the apparent energy of activation of 13.32 k.cal./g. mole of the present study with previous work. This value compares favorably with the data of Pease who found 13.4 k.cal./g. mole for a partially deactivated supported copper catalyst at temperatures between 0° and 60°; and it compares well with the data of Grassi (*4*) which gives a value of 12.00 k.cal. between 150° and 200°. Of interest also are the results of Greenhalgh and Polanyi (*5*) who studied the rates of hydrogen exchange during hydrogenation of ethylene over reduced copper oxide, as well as the rate of ortho-para and deuterium-hydrogen conversion over the same catalyst. Data of Greenhalgh and Polanyi on the hydrogenation of ethylene are not complete nor precise enough

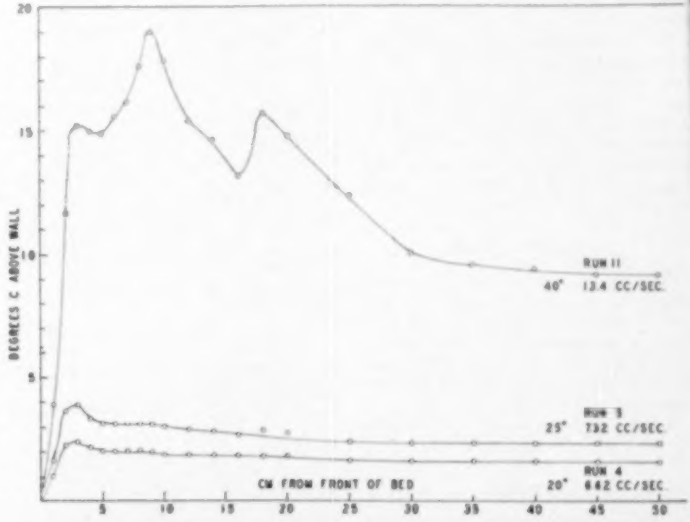

Fig. 9. Axial Temperature Profiles in Non-Isothermal Experiments.

to give an accurate estimate of the activation energy directly. However, they do state that the hydrogenation at 20° was rapid and reached the half completion mark at about 30 min. This compares favorably with run number 78 of Pease wherein at 20° the half-way mark was reached in slightly more than 20 min. Greenhalgh and Polanyi noted no exchange reactions or ortho-para conversion as long as ethylene hydrogenation was proceeding and thus concluded that while the catalyst definitely does cause molecular scission of the hydrogen, the presence of the ethylene results in so rapid a consumption of hydrogen atoms that the reverse process of hydrogen combination, and hence ortho-para or deuterium-hydrogen exchange never takes place. Phrased differently this means that the slow process in the hydrogenation of ethylene over copper may well be bound up with the scission of hydrogen-hydrogen bonds. This is further attested if we assume, in the absence of better information, that the hydrogenation kinetics of Greenhalgh and Polanyi are approximately the same as those of Pease because they followed the same techniques as Pease in catalyst preparation. These authors observed an activation energy for ortho-para conversion of 14.0 k.cal. which compares well with Pease's value of 13.4 k.cal. for the activation energy of the hydrogenation.

The energy of activation of present experiments with and without water poisoning had the same energy of activation. One may presume from this result that water poisoning is not bound up with the slow process involving hydrogen but is more likely associated with the adsorption of ethylene on the surface and as such probably is a steric effect.

Taylor and Joris (*16*) studied the hydrogenation of ethylene over a catalyst similar to the one employed in this work. The proportions, however, were 25 mole % Cu compared with 50 mole % in the present catalyst. The energy of activation in the previous study was lower, 7.3 k.cal./g. mole compared with the present value of 13.3.

Acknowledgment

This work was supported by a fellowship and project for the study of reaction kinetics and heat transfer in flow systems sponsored by the Shell Oil Co., Inc. The authors wish to express their appreciation for the interest and cooperation of this company.

Copper of high purity was supplied by the Phelps-Dodge Copper Co.

Notation

A = frequency factor in Arrhenius equation

b = adsorption equilibrium constant

E = energy of activation

k' = specific surface reaction rate constant g. moles/(sec.)(cc. of catalyst chamber)

k'' = over-all rate constant, $(k'b_a)$

N = moles/sec. total gas flowing in reactor at any point

p = partial gas pressure in atmospheres

R = gas constant

S = space velocity, moles feed gas/(sec.)(cc. catalyst) (N_i/V)

T = absolute temperature

t = time in seconds

V = volume of reactor in cubic centimeters

y = mole fraction in gas phase

$\Delta y = y_{ot} - y_{io}$

θ = fraction of available catalyst surface covered

π = total pressure in atmospheres

Subscripts:

a = hydrogen

b = ethylene

c = ethane

i = inlet conditions of reactor

o = outlet conditions of reactor

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Discussion

E. E. Gullekson (California Research Corp., El Segundo, Calif.): The definition of the apparent reaction order and the evaluation of reaction rates have been ably accomplished by application of methods which represent significant contributions to the science of kinetics. Of particular value in this paper, is the lucid demonstration of the type and magnitude of the errors that may be encountered in the investigation of kinetics.

As Dr. Wilhelm has stated, the use of flow-type investigations is becoming increasingly important because of widespread application of chemical phenomena to industrial purposes. The flow-type kinetic analysis is usually considerably superior to the static type for this purpose, and usually results in information which approaches the reliability and practicability of that which may be obtained in pilot scale or semicommercial scale investigation.

The work described here is concerned with small conversions per pass. Usually, however, in the industrial application of a chemical reaction, economics requires that the conversion be selected so that the recycle of unreacted materials will not be excessive. Would the authors care to state whether a different approach to this problem must be made in the event of higher conversions?

R. H. Wilhelm: Yes, as higher conversions are taken, the rates of point, rates of heat release of course, are greater, and temperature gradients are obtained through the reactor. We, as well as many others, are in the process of studying the design procedures that may be applicable to the nonisothermal reactor in which you nevertheless attempt to maintain the wall as a fixed temperature value. Considerable progress has been made along this line. We have been successful to date in predicting by appropriate heat-balance calculations, the gradients that are measured experimentally with the same reaction. The information obtained in this paper serves as a background for further evaluations.

(*Presented at Tenth Regional Meeting, Los Angeles, Calif.*)

THERMODYNAMIC PROPERTIES OF *n*-HEPTANE

EDWARD B. STUART, KUO TSUNG YU and JAMES COULL

University of Pittsburgh, Pittsburgh, Pennsylvania

Thermodynamic properties of *n*-heptane have been calculated from P-V-T data and presented in a pressure-enthalpy diagram as well as in tabular form. The range covered is from 1 to 300 atmospheres and from 209.08° to 1800° F.

MODERN developments in the synthesis and recovery (*3, 9, 14*) of hydrocarbons from basic materials over wide ranges of pressure and temperature have created a need for thermodynamic charts of the higher molecular weight compounds. This paper presents the thermodynamic properties of *n*-heptane calculated from *P-V-T* data in the form of a pressure-enthalpy diagram and tables. (*See* diagram on p. 312.)

P-V-T Data

Beattie and Kay (*2*) reported the experimental *P-V-T* data for the superheated region of *n*-heptane from 7.12 to 351.50 atmospheres and from 30 to 350° C. These data were used later by Smith, Beattie and Kay (*13*) to determine the constants for the Beattie-Bridgeman equation of state. When the experimental isometrics are compared with those calculated from the Beattie-Bridgeman equation in a *P-T* plot, excellent agreement is found only at a density below one half of the critical. It is observed also that the experimental isometrics above one half of the critical density are substantially straight. In view of the inconsistency between the experimental data and the Beattie-Bridgeman equation of state, two methods were used to extend the *P-V-T* data. For those densities below one half of the critical, data are extended analytically by using the Beattie-Bridgeman equation; while for the densities above this value, data are extended graphically by an extrapolation of the experimental isometrics. Such extrapolated data, however, are only a small portion of the total data used in the present calculation.

Properties in Ideal Gas State. Properties in the ideal gas state were taken from A.P.I. research project 44 (*1*); Tables 2v, 2u and 2t contain specific heats, enthalpy and entropy respectively. Data reported range from 0 to 1500° K.

Properties in Saturated State. Young (*16*) reported the vapor pressure and specific volumes of vapor and liquid for a number of hydrocarbons including *n*-heptane. His data, covering from 0.01508 to 26.950 atmospheres and 0 to 266.85° C., are in agreement with later, less extensive work by Beattie and Kay (*2*). Original data of Young, after a careful examination, have not been smoothed. In the present calculation, polished data were used to evaluate the latent heat of vaporization by the Clapeyron equation. The calculated latent heat of vaporization is in agreement with those reported by Young (*16*).

Method of Evaluation. For the data below one half of the critical density in which the Beattie-Bridgeman equation of state may be used with high accuracy, the thermodynamic network can be calculated analytically (*12*). For the data above one half of the critical density, the graphical method of evaluation is necessary. To confine the whole calculation into a single method of evaluation, the graphical method of residual volume as outlined by Deming and Shupe (*4-6*), Edmister (*7*) and York (*15*) is used.

Comment

The recent publication of the properties of benzene (*10*) and *n*-butane (*11*) provides hydrocarbons with which a comparison can be made. It is of interest to note that the slope of the isotherms and isentropics from *n*-heptane are closer to benzene than to *n*-butane. This similarity between the properties of *n*-heptane and benzene has been shown over a short range by Gilliland (*8*).

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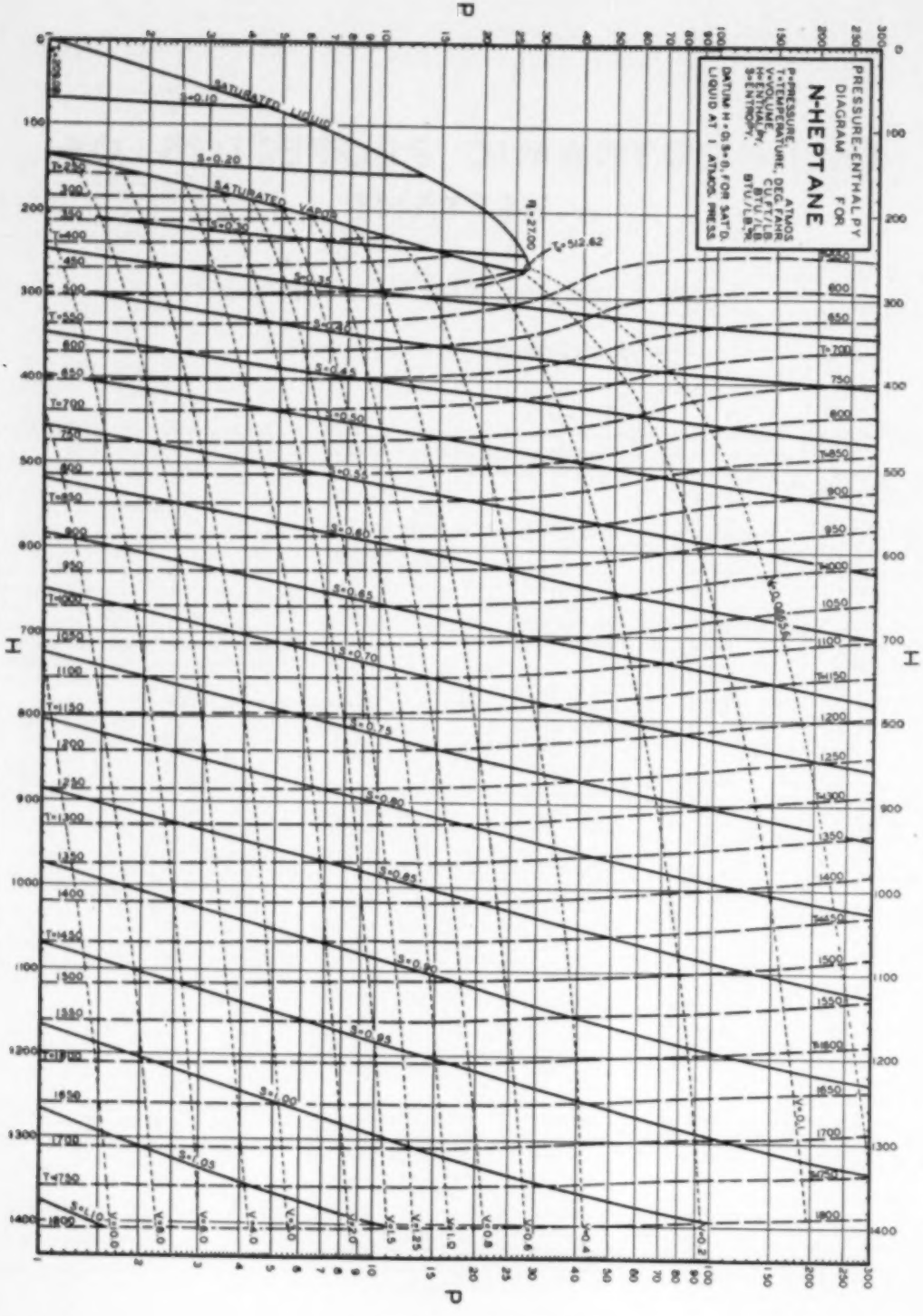
Note: Tables are on file (Document 2753) with the American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C. Data can be obtained by remitting 50 cents for a microfilm and 50 cents for photoprints.


N-HEPTANE
PRESSURE-ENTHALPY DIAGRAM FOR
P=PRESSURE, ATMOS
T=TEMPERATURE, DEG FAHR
V=VOLUME, CU FT/LB
H=ENTHALPY, BTU/LB.
S=ENTROPY,
DATUM H=0, S=0, FOR SAT'D LIQUID AT 1 ATMOS. PRESS.
SATURATED LIQUID
SATURATED VAPOR
P=27.00
T=512.62
H
P

PRODUCTION OF AROMATICS

C. H. MARSHALL

Humble Oil and Refining Company, Houston, Texas

PRIOR to the declaration of war in 1914, aromatic hydrocarbons such as benzene, toluene, and xylenes were produced strictly as by-products of the coal-tar industry and were consumed chiefly in the manufacture of dyes for the textile industry. Utilization of these tars dates from the discovery of the first aniline dye by Perkin in 1856. At the beginning of the twentieth century production of toluene in the United States probably did not exceed 750,000 gal./yr. (50 bbl./calendar day), but with the outbreak of World War I the demand for benzene and toluene as raw materials in the manufacture of explosives skyrocketed.

Toluene which normally sold for less than 25 cents/gal. could not be bought in quantity for $5.00/gal. This was due primarily to trinitrotoluene assuming first rank among explosives because of its low melting point, its safety in handling, its nonacidity, and the ease with which its time of explosion can be controlled. By 1918 the toluene output had reached some 20,000,000 gal./year (1,300 bbl./calendar day) and practically all the increase was possible because of the recovery processes for extracting toluene from coke-oven and city gas supplies. The extreme need for explosives during this period prompted even the production of small quantities of toluene from petroleum by thermal decomposition of the nonaromatic contaminants present in virgin naphtha fractions. Obviously, this resulted in extremely expensive toluene since even the better aromatic-type crudes contain only some 35% virgin toluene in the 200-250° F. fraction and it would be necessary to decompose the remaining 60-65% of the fraction in order to obtain sufficient purity to make the toluene suitable for nitration. The reluctance of the coal-tar industry to install additional equipment for the manufacture of toluene may well be understood when a comparison of the extremely low yields obtained from coal tar is made with the somewhat higher yields from petroleum. This fact coupled with a lower initial investment for the petroleum plants tended to discourage expansion of the coal-tar industry specifically for aromatic production.

During the interim period 1918-38, the status of aromatics production was rather stable with regard to additional plant installations. Toluene was generally considered a coal-tar by-product until the late thirties of the current century. At that time toluene requirements of the United States for explosives during wartime were estimated at some 21,000,000 gal./month or about 16,000 bbl./calendar day. Supplies of this aromatic from the coal-tar industry approximated 2.5 to 3,000,000 gal./month of nitration-grade toluene. Therefore, the Ordnance Department began to take steps to establish plants for the recovery and synthesis of toluene from petroleum. Two commercial processes were utilized for the manufacture of aromatics from petroleum. The first of these was a recovery process that isolated naturally occurring toluene fractions from petroleum crudes by distillation. This was followed by some purification means such as extractive distillation and acid-treating plus rerunning to eliminate high boiling compounds from the desired aromatic. The second was a synthetic process that utilized suitable catalysts to dehydrogenate naphthenes such as methylcyclohexane to give the corresponding aromatic. The information presented below will be devoted to the production of aromatics by the synthetic process known as hydroforming.

At the outbreak of World War II in 1939, most of the commercial hydroforming units were still in the planning stages. Under the impetus of war, a number of these plant installations was completed and placed in service in the U. S. prior to and during the period of the participation of the U. S. in the war. One of the first commercial hydroforming units to be placed in operation for the production of high-purity aromatics and the largest in the world to date, is the one operated by Humble Oil & Refining Co. at Baytown, Tex. During World War II this plant supplied more than one half the toluene that went into TNT for the U. S. Armed Forces. In addition to the prime purpose of maximum production of nitration-grade toluene for TNT manufacture, its operations were integrated with those of Humble's Baytown refinery to enable substantial contributions to the production of 100 octane aviation gasoline. Products from the process boiling above and below toluene constituted valuable blending components for aviation gasolines, due particularly to the exceptionally good rich-mixture antiknock characteristics of certain aromatics, such as xylenes contained therein.

Description of Hydroforming Process. The hydroforming process consists of the catalytic treatment of naphthas in the vapor phase at elevated temperatures and pressures in the presence of hydrogen; the primary conversion occurring is the catalytic dehydrogenation of an alicyclic hydrocarbon containing a six-carbon naphthene ring to the corresponding compound containing a benzene ring accounting for the fact that

in hydroforming there is a net production of hydrogen. Three equations illustrating the principal reaction are shown as follows:

Cyclohexane	$\xrightarrow{\text{Catalyst}}$	Benzene + $3H_2$ − 53,010 cal. (at 980° F.)
Methylcyclohexane	$\xrightarrow{\text{Catalyst}}$	Toluene + $3H_2$ − 52,750 cal. (at 980° F.)
1,2 Dimethylcyclohexane	$\xrightarrow{\text{Catalyst}}$	O-xylene + $3H_2$ − 52,970 cal. (at 980° F.)

While the hydroforming process is rather specific for effecting the abovementioned type of dehydrogenation reaction, its application to petroleum naphthas for the synthesis of aromatic-type products is accompanied by a number of secondary or side reactions. These side reactions, which are influenced by the composition of the naphtha feed and which are subject to considerable control by selection of catalyst and of operating conditions such as temperature, pressure, and reaction time, usually include the following: (1) dehydrocyclization of normal paraffins, presumably through the intermediate formation of an olefin, to produce an aromatic hydrocarbon, e.g., conversion of normal heptane to toluene; (2) rearrangement reactions of naphthenes or paraffins, such as isomerization; (3) various pyrolytic decompositions, such as fission of five-carbon naphthene rings, dealkylation of ring sidechains, and cracking of paraffins; (4) formation of small quantities of high boiling material, probably through alkylation and condensation mechanisms; (5) hydrogenation of olefins, which proceeds essentially to completion since the hydroforming catalyst also catalyzes olefin hydrogenation under the reaction conditions, wherein a relatively large concentration of free hydrogen is present; and (6) decomposition of sulfur-containing compounds. Of these side reactions, pyrolytic decomposition is the most extensive with virgin naphtha feed stocks because the hydroforming reaction, to obtain the desired conversion to aromatics, is conducted usually at temperatures in the order of 900° to 1000° F., at which temperature level the rate of thermal cracking is significant. Hydrogenation of olefins is usually the most important side reaction occurring with cracked naphtha feed stocks.

In conducting the hydroforming process, some carbon is produced and deposited on the catalyst as coke; such carbon is periodically removed from the catalyst by oxidation, restoring the catalyst essentially to its original activity. An important feature of the hydroforming process is that it represents a dehydrogenation process in the presence of hydrogen added in excess of that produced from the dehydrogenation of naphthenes. This excess hydrogen is provided by recycling a portion of the hydrogen-rich light gas produced in the process. Advantages accruing to recycling this 70% hydrogen gas are (1) prolonging the life of the catalyst, (2) reducing feed stock degradation to carbon and noncondensable hydrocarbon gases and, (3) providing additional heat input to the endothermic hydroforming reaction by preheating the hydrogen recycle.

The hydroforming process is employed by the petroleum refining industry both to produce aromatic compounds of high purity for specialized uses as solvents, chemical intermediates, and aviation gasoline blending agents, or to elevate the antiknock quality of petroleum naphthas boiling in the range of 200° to 450° F. for inclusion in premium quality gasolines. The most extensive postwar application of hydroforming is the processing of straight-run petroleum naphthas for improvement of antiknock quality in the production of premium automotive gasolines. It offers a number of advantages over the older thermal reforming process for upgrading the gasoline quality of the relatively low octane number virgin naphthas. In addition to effecting a greater improvement in octane quality for a given gasoline yield than does the thermal process, hydroforming produces a stable, low-sulfur gasoline that is usually doctor sweet; little or no finishing treatment is required. Stability to both color degradation and gum formation is achieved because of the negligible concentration of olefins and particularly of diolefins in the hydroformate. Flexibility of the hydroforming process is apparent in that product octane quality can be adjusted to the desired level, over a considerable range, to obtain the optimum balance between yield and octane number improvement.

From the nature of the hydroforming reaction, feed stocks containing the largest percentage of suitable naphthenic compounds are those from which hydroformates having the highest octane number can be produced. In general, naphthas from Gulf Coast crudes have a considerably higher naphthene content than do those from Mid-Continent crudes. Mid-Continent naphthas usually are slightly more naphthenic than those from such crudes as East Texas and West Texas. The naphthene content of a virgin naphtha from a given crude source usually increases with an increase in naphtha boiling point, but of even greater significance is the fact that the difference in octane rating between a naphthene hydrocarbon and the corresponding aromatic compound tends to be markedly greater in the case of the higher boiling, or heavier molecular weight, compounds. This trend is illustrated by Motor Method octane number blending values for certain representative hydrocarbons. Cyclohexane, the lowest boiling naphthene with a six-carbon ring, has a boiling point of 177° F. and an octane rating 97; benzene, the corresponding aromatic compound has a boiling point of 176° F. and an octane rating of 90.5, lower than that of the parent naphthene. The next higher boiling naphthene having a six-carbon ring is methylcyclohexane, which boils at 213° F. and has an octane rating of 84; in this case the aromatic derivative, toluene, has a boiling point of 231° F. and an octane rating of 112. Continuing up the homologous series, the mixed *cis* and *trans* isomers of 1,4 dimethylcyclohexane have an octane rating of about 65 whereas the aromatic derivative, paraxylene, has an octane rating of 127. While there is a scarcity of octane data on individual compounds of still higher boiling point, there is ample evidence that the corresponding naphthene and aromatic compounds exhibit octane number differences in the same order of magnitude as the preceding example. It is emphasized that the octane ratings given here were measured in a blend of the particular compound with a standard paraffinic-type gasoline base of known octane quality; straight octane ratings on the pure compounds and blending values in other gasoline bases would be considerably different in some cases.

As a result of these considerations, the heavier naphtha fractions are preferable as hydroformer feed when operating a unit of this type strictly for motor gasoline octane improvement. The naphtha fraction boiling from about 250° F. up to 400° F., the normal gasoline end point, has been found to be the most desirable feed in a situation where hydroforming capacity is limited by factors other than feed stock availability. A 330° F. end-point feed is used in certain cases where the hydroformate is being used exclusively in premium-grade gasolines having a sharply limited back-end volatility specification. The naphtha fraction boiling from 200° to 250° F. which contains the methylcyclohexane, offers a good, but lesser, opportunity for octane improvement. The naphtha boiling below 200° F. containing the cyclohexane preferably is omitted from the feed when hydroforming for gasoline octane number improvement. In some

The heart of superfractionators that handle all distillation operations including preparation of various types of hydroformer feed is located on the panel boards of this air conditioned control room at Baytown refinery.

cases where adequate capacity exists, heavy naphtha boiling in the range of 400-450° F. may be included in the hydroformer feed because a substantial portion of this fraction can be converted under severe reaction conditions to material boiling below the 400° F. gasoline end point, thereby resulting in additional gasoline recovery (*2*).

Baytown Ordnance Works Wartime Operations. The Baytown Ordnance Works was placed in operation by Humble Oil & Refining Co. for the United States Government in September, 1941, three months before Pearl Harbor to produce maximum quantities of nitration grade toluene. As originally conceived, and as is shown in Figure 1, production of toluene involved the processing of crude naphthas cut to about 400° F. end point in a three-tower superfractionation unit for stabilization, the preparation of a pentane to 200° F. end point light-blend naphtha, and a 200-250° F. boiling range fraction for hydroformer feed stock. Since toluene was the desired product, the crude naphtha cut points at the primary distillation units were adjusted for the recovery of about 95 per cent of the methylcyclohexane in the crude. At the Baytown Ordnance Works distillation equipment the hydroformer feed cut points were adjusted so that essentially no methylcyclohexane or toluene was lost in the light-blend naphtha or naphtha for reforming stock returned to the refinery. The fraction containing essentially all the methylcyclohexane and virgin toluene in the crudes run in the Baytown refinery was charged to the hydroformer for the production of synthetic toluene. Some figures on the toluene producible by severely hydroforming several 200° to 250°F. virgin naphthas of varying methylcyclohexane content are shown in Table 1. The

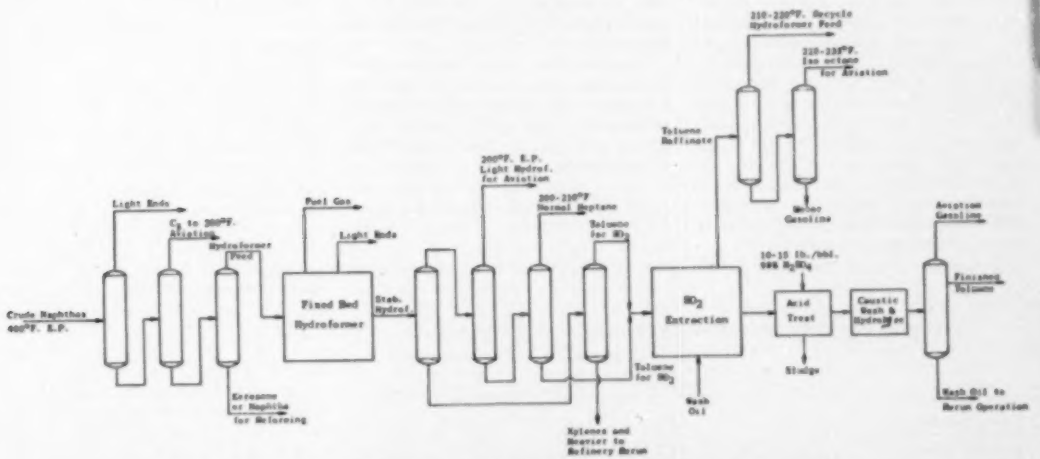


Fig. 1. Simplified Flow Diagram—Wartime Operations at Baytown Ordnance Works.

toluene yields above the theoretical are the result of secondary reactions involving aromatization of paraffins and isomerization of five-carbon naphthene rings to six-carbon rings, followed by dehydrogenation. The actual disappearance of methylcyclohexane was in the order of 85 to 90%.

Processing the stabilized hydroformate was accomplished in a four-tower operation for the production of a light hydroformate fraction (200° F. end point), a normal heptane stream, a toluene-rich feed stock for the sulfur dioxide plant, and a heavy aromatic product for subsequent rerunning in the refinery to recover the xylenes for aviation gasoline. The toluene concentrate fraction was solvent-extracted at temperatures in the league of −25° F. with liquid sulfur dioxide for the purification of this aromatic. Extraction of toluene with liquid sulfur dioxide results in an extract phase containing some 65-70% aromatics. For nitration purposes, an aromaticity of 98-99% was required and additional purification of the toluene extract was necessitated. Since the nonaromatic impurities in the extract boil closely to the desired aromatic, separation by distillation was not feasible. Therefore, a washing operation was incorporated in which heavy paraffins were applied to the aromatic-sulfur dioxide mixture to displace the light nonaromatics in the toluene distillation range. Removal of these heavy paraffins from the toluene then becomes an easy matter by distillation. Steps involved in the finishing of the extract from the final wash operation consisted of (1) a 10-15 lb./bbl. treat with 98% H_2SO_4 to remove small quantities of olefins present in the final extract, (2) caustic hydrolysis at 300° F. for the conversion of sulfated hydrocarbons, and (3) a final rerun operation taking finished toluene as a sidestream to separate the desired product from high boiling paraffins introduced by the wash oil and from polymers formed in the acid-treating operation. A 50-100 bbl./day slop fraction taken as an overhead stream in the final rerun operation permitted the removal of moisture from nitration grade toluene, thereby eliminating cloud-point difficulties experienced during the early stages of operations on toluene.

Test work at all of the units showed that substantial surplus capacity was available throughout the plant. Since maximum toluene production was desired, a number of outside stocks was purchased to supplement the crude naphthas furnished by the Baytown refinery. These included crude naphthas imported to Baytown from other refiners, a methylcyclohexane concentrate for hydroformer feed, and a toluene hydroformate for sulfur dioxide plant feed stock. However, these stocks failed to utilize all the hydroforming capacity and as a result, a 200-250° F. fraction from thermally cracked naphtha was used for the production of additional toluene. For maximum toluene production, processing cracked naphtha is a desirable operation, although from an octane number standpoint, the cracked material represents a somewhat poorer hydroformer feed than virgin naphthas. Cracked naphthas are of higher initial octane quality than the virgin naphthas, and, therefore, offer less chance of octane number improvement upon hydroforming. In addition, carbon production from the cracked naphtha is some 50% higher than for a virgin naphtha of the same boiling range under comparable operating conditions. For these reasons, hydroforming cracked naphthas usually does not appear attractive in postwar operations for octane number improvement, although it was desirable for maximum toluene production during the war years. A novel feature of cracked-naphtha hydroforming is that the hydrogenation of the olefins in the cracked feed, which proceeds readily under reactor conditions, is a strongly exothermic reaction; the heat released thereby substantially offsets that absorbed by the endothermic hydroforming reaction. Thus, either a lower reactor inlet temperature may be employed or higher conversion of naphthenes to aromatics may be obtained.

Two interesting operations were conducted during the war at the Baytown Ordnance Works to obtain additional hydroformer feed and to produce high quality aviation gasoline blend stocks. Since aviation gasoline was limited by suitable aromatics for rich mixture performance, there was considerable interest in maximizing incidental xylene output. Processing a narrow cut feed stock (200-250° F.) at the hydroformer resulted in an incidental xylene fraction of about 95% purity. As the boiling range on the hydroformer feed was increased, xylene production also increased but purity decreased somewhat. Laboratory work showed that a 90% xylene blending agent could be manufactured by widening out considerably on the boiling range of the hydroformer feed produced at the crude naphtha units. Consequently, the end point of the hydroformer feed was increased to a range of 260-275° F. depending on the paraffin content of the crude naphthas charged to the plant, and at the end of the war approximately 2,500 bbl./day of incidental xylenes were being produced.

The second operation conducted was known as a recycle raffinate operation. Laboratory analyses showed that the 220-235° F. fraction from the toluene raffinate produced at the sulfur dioxide plant contained substantial quantities of isooctanes of better octane quality than marginal stocks included in aviation gasoline. It was possible to charge this raffinate to the feed preparation unit taking overhead a methylcyclohexane-rich stream for recycle to the hydroformer and an isooctane fraction for aviation gasoline blending. This was a segregated operation which permitted approximately 85% of the methylcyclohexane in the raffinate to be recovered while producing additional aviation gasoline blend stocks.

Postwar Aromatic Production. At the close of World War II, operations at the Baytown Ordnance Works were suspended by the United States Government; however, after a brief interval the plant was leased for several months by the Humble Oil & Refining Co.; and the production of extracted toluene and xylenes was then begun on a temporary basis. After several months' operations negotiations were completed with the government for the purchase of the plant with all the attendant equipment, and to date, the processing of virgin naphthas for octane improvement and the production of high purity solvents and aviation blend stocks have consumed the entire plant capacity. The solvent products currently produced are 98-99% pure toluene, a mixed xylene product of 98-99% aromaticity, a 95% pure C_9 aromatic fraction, and a 90% C_{10} aromatic fraction. Pertinent tests on the finished solvents are presented in Table 2.

As was the case during the war, 400° F. end-point crude naphthas cut from crude batteries and pipe stills are charged to the crude naphtha rerun units for the preparation of hydroformer feed stock. This operation is carried out in a three-tower system shown in Figure 2.

TABLE 1.—YIELDS OF TOLUENE FROM 200°–250° F. VIRGIN NAPHTHAS

Feed Stock Type	Feed Stock Analysis		Toluene Yield, vol. % of Feed	
	Methylcyclohexane, vol. %	Toluene, vol. %	Theoretical	Actual
Highly naphthenic	33.6	0.0	26.0	25.4
Moderately naphthenic	29.2	0.3	24.7	21.4
Aromatic-naphthenic	22.7	10.9	29.8	28.7
Moderately paraffinic	20.1	5.1	19.9	23.0
Highly paraffinic	14.9	2.8	15.2	18.2

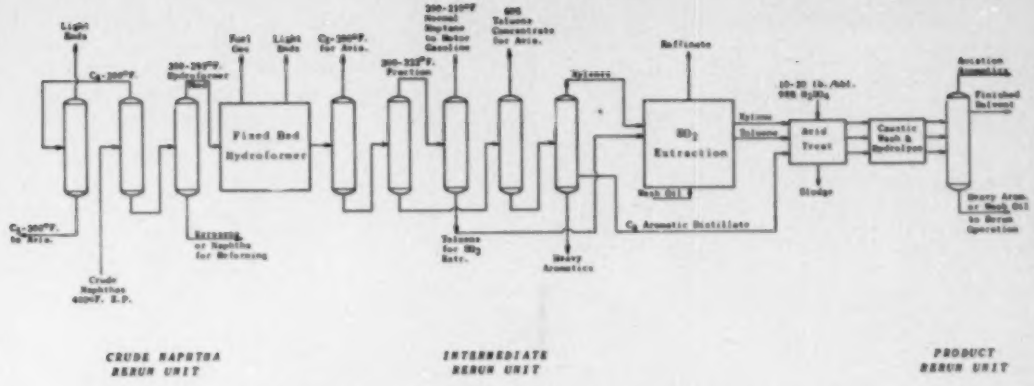


Fig. 2. Simplified Flow Diagram—Postwar Operations at Baytown Ordnance Refinery.

A butane to 200° F. end-point light-blend naphtha fraction is produced from the first 50-plate superfractionator and this fraction is subsequently stabilized in a 30-plate tower for removal of the butane contained therein. Essentially complete removal of the butane must be effected in this stabilization operation to insure isopentane purity when further processing the light-blend naphtha for recovery of isopentane, isohexane, and isoheptane fractions in the aviation blend stock operation. The 200-400° F. bottoms stream from the first 50-plate superfractionator is then charged to the final tower in the crude naphtha rerun unit from which is taken as an overhead stream the feed stock for the hydroforming unit. The type of crude naphtha being charged to the crude naphtha rerun units determines the boiling range of the hydroformer feed that will be produced. Normally, a 200-300° F. end-point fraction is segregated for the hydroformer to produce toluene, xylenes, and a C_9 aromatic fraction; however, during the times when highly naphthenic coastal-type virgin naphthas are processed at this unit, the end point on the hydroformer feed is elevated to 345-350° F. in order to include C_{10} naphthenes for the production of a C_{10} aromatic fraction. Listed in Table 3 are the boiling points of several C_9 and C_{10} aromatics. Consideration of the individual naphthenes and aromatics will give some indication of the elevation in boiling point that accompanies the hydroforming of a C_9 and C_{10} naphthene.

In the case of the C_9 and C_{10} aromatic products, inclusion of naphthenes that will result in aromatics boiling in the desired distillation range is imperative for the production of the specified aromatic purity. On the other hand, the choice of the hydroformer feed cut point must be made to exclude essentially all of the nonaromatic material boiling in the range of the desired product that will dilute the purity of these products below the specified minimum. For example, maintaining the hydroformer feed end point at 295° F. for C_9 aromatic production permits inclusion of naphthenes, primarily trimethyl cyclohexanes, that after hydroforming, will result in aromatics boiling in the desired distillation range (300-350° F.). Processing a higher end point hydroformer feed to include C_9 naphthenes such as methylethylcyclohexanes and propylcyclohexane (boiling points in the range of 305-315° F.) will result in dilution of the aromatic distillate below the specified purity on the aromatic solvent. For this reason, the entire production of C_9 and C_{10} aromatics is necessarily a synthetic product. For the crude naphthas processed at Baytown, plant operations have indicated that for satisfactory C_9 aromatic quality the end point on the hydroformer feed must be controlled to about 295° F., and for the C_{10} aromatic a range of 345-350° F. is satisfactory.

TABLE 2.—INSPECTIONS ON CURRENT PRODUCTION SOLVENT AROMATICS

	Toluene	Xylenes	C_9 Aromatics	C_{10} Aromatics
IBP °F.	228.9	275	315	365
10% Distilled at °F.	.....	.....	324	370
50% Distilled at °F.	.....	.....	326	375
90% Distilled at °F.	.....	.....	330	395
End Pt. °F.	232.5	293	370	425
Tag Closed Cup Flash °F.	.....	80	100	150
% Aromatics	98–99	98–99	95	90

Recovery of the solvent products from the stabilized hydroformate for subsequent finishing is accomplished in a series of distillation towers known as the Intermediate Rerun Unit (Fig. 2). The major products from this unit are summarized in Table 4.

The finishing steps applied to obtain toluene and xylenes from the distillates containing these aromatics follow much the same pattern as was employed during wartime operations, i.e., sulfur dioxide extraction followed by acid treating and rerunning to obtain a heart-cut, color stable product. It is interesting to note that an approximate analysis of the product rerun unit feed on xylenes indicates that the xylenes consist of some 43% of the meta-isomer and 17% of the para-isomer, with the remaining 40% being equally divided between ortho-xylene and ethyl benzene. Processing of the higher molecular weight C_9 aromatic distillate involves only

TABLE 3.—BOILING POINTS OF VARIOUS C_9 AND C_{10} NAPHTHENES AND AROMATICS

Aromatic Produced from Corresponding Naphthene	B.P. of Compound, °F. Naphthene(1)	Aromatic(1)
1, 2, 3 Trimethyl Benzene	293	349
1, 2, 4 Trimethyl Benzene	289	337
1, 3, 5 Trimethyl Benzene	285	328
1 Methyl, 2 Ethyl Benzene	309	329
1 Methyl, 3 Ethyl Benzene	301	324
1 Methyl, 4 Ethyl Benzene	303	323
Propyl Benzene	311	319
Isopropyl Benzene	310	306
1, 2, 3, 5 Tetramethyl Benzene	325–326	386
1, 2, 4, 5 Tetramethyl Benzene	332–340	385
1,3 Dimethyl, 5 Ethyl Benzene	338	365
1, 4 Diethyl Benzene	345–349	362
1, 3 Diethyl Benzene	333	357
1 Methyl, 2 Isopropyl Benzene	329	348
1 Methyl, 3 Propyl Benzene	340	362
n-Butyl Benzene	357	361
Isobutyl Benzene	357	358

TABLE 4.—PRODUCT STREAMS FROM STABILIZED HYDROFORMATE

Product	Boiling Range, °F.	% Aromatics
Light hydroformate	Pentane—200	2–3
Normal heptane distillate	200–210	5–10
Toluene distillate	210–222	45–50
Toluene concentrate	222–225	60–65
Xylene distillate	225–300	55–65
C_9 aromatic distillate	300–450	98–99
Heavy aromatics	450 and heavier	99

treatment with 98% H_2SO_4 and redistillation to insure good color stability of the finished product. Production of the finished C_{10} aromatic fraction is accomplished from an aromatic distillate in a manner similar to that employed in obtaining the finished C_9 aromatic product, i.e., acid treating and rerunning of the aromatic distillate.

Although the production of high purity toluene and xylenes for solvents, as outlined here, requires use of some type of precise extraction process, any refiner who might have a combination of hydroforming and distillation equipment may utilize them to recover from the hydroformate components suitable for high quality motor or aviation gasoline. It is possible to segregate a toluene concentrate that normally contains 60-65% of toluene. This provides an excellent blend stock for aviation gasoline, since in addition to containing toluene that possesses an extremely high rich-mixture rating, the nonaromatic material in this boiling range is of a quality that is better than marginal base stock available for aviation blends. Further, the 200°F. end-point light hydroformate also contains appreciable isohexane and isoheptane fractions that may be recovered by fractionation for use as aviation gasoline blend stocks.

Acknowledgment

Acknowledgment is gratefully given to G. H. Shipley and G. W. Wilson for information supplied concerning operations at the Baytown Ordnance Works. Thanks are also due Dr. A. A. Draeger, G. T. Gwin, and C. J. G. Leeseman, authors of the paper on "Hydroforming" from which was taken the information describing the hydroforming process.

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Discussion

George E. Liedholm (Shell Development Co., San Francisco, Calif.): As a member of the toluene technical committee, I was in a position to watch the production of this unit raised from a design of 2500 bbl./day of nitration-grade toluene, initially, to a figure of 4700 bbl./day at the end of the war. The conversion of this unit from a wartime facility to peacetime use represents progress towards increasing our standard of living out of the product of an effort that, at one time, was considered expendable for war and military purposes. Incidentally, the Humble plant is unique in that it is the only one which employed liquid-liquid extraction for concentration and purification of toluene. Most other toluene plants, including those using the hydroforming step, employed either azeotropic fractionation or, in a majority of cases, extractive distillation.

Can you charge a combined toluene-xylene stream to the sulfur dioxide extraction plant or is it necessary to batch these fractions through?

C.H. Marshall: You can charge a combined toluene-xylene stream. For a time several years ago we were charging combined toluene-xylene distillate to the sulfur dioxide plant and separating them by distillation after solvent extraction.

G. E. Liedholm: Does this apply to the higher aromatics as well?

C. H. Marshall: We have not tried that and I am not sure.

G. E. Liedholm: Do you segregate the various xylene isomers after recovery in the liquid-liquid extraction plant?

C. H. Marshall: You mean by crystallization or some other means of separating the xylene isomers?

G. E. Liedholm: Yes.

C. H. Marshall: No attempt is made to separate the xylene isomers.

Anonymous: Is there any commercial production of toluene from straight chain hydrocarbons? I bring up that question because there have been a number of articles stating that cyclization of, say, normal heptane can be used for the production of toluene.

C. H. Marshall: I know of no commercial installation at present although there has been considerable laboratory work done on the cyclization of straight chain paraffins.

Frank J. Smith (Pan American Refining Corp., Texas City, Tex.): What is the treatment you give the C_9 and the C_{10} aromatics? Is it a single acid wash or a double acid wash?

C. H. Marshall: It is a double acid wash. The fresh acid is charged to the second stage and the acid sludge from this stage is then used in the first stage to treat the extract from the sulfur dioxide plant.

F. J. Smith: What is the amount of the acid treat? Is it approximately 15 lb./bbl.?

C. H. Marshall: Usually it is somewhere between 10 and 20 lb./bbl.

Charles W. Perry (Phillips Chemical Co., Bartlesville, Okla.): What aromaticity and naphthenic contents can you stand in your feed naphtha?

C. H. Marshall: You mean in the 200-250° F. fraction?

C. W. Perry: Yes.

C. H. Marshall: We charge three different types of feed stocks—a highly aromatic virgin naphtha, a highly naphthenic feed stock and a stock of high paraffin content. The highly aromatic feed stock contains about 23% methylcyclohexane and some 10-12% aromatics in the 200-250° F. boiling range. On the highly naphthenic feed, the naphthene content is about 34% of this fraction with little or no toluene present. For the paraffinic feed stock, the methylcyclohexane content is in the league of 15% with 2-3% toluene in this fraction.

C. W. Perry: Is there a limiting upper methylcyclohexane content that you can use in the hydroforming process and get good yields of toluene?

C. H. Marshall: I don't know, although I can say that we have noticed no evidence of this in processing our feed stocks.

Anonymous: What is the nature of the stream labeled heavy aromatics and what use is made of them?

C. H. Marshall: The heavy aromatics stream on an Engler distillation has an initial boiling point of about 450° F. with 80% distilled at around 700° F. Presently, this stream is returned to the refinery for rerunning. The volume of this stream is rather small, being about 0.5-1.0% of the hydroformer feed.

(*Presented at Eleventh Regional Meeting, Tulsa, Okla.*)

Council met for business during the Swampscott meeting. In order counterclockwise around the table are: Dayton Wilde, Walter Whitman, M. G. Molstad, W. Burt, C. R. DeLong, W. L. McCabe. At head of table, S. L. Tyler, T. H. Chilton, C. G. Kirkbride, F. J. Curtis.

One of the novel features of the meeting was the small industrial exhibits in the lobby of the New Ocean House meeting headquarters. Here T. E. Stretton of Eastern Gas & Fuel chats with Howard Hamacher of A. D. Little, Inc., in front of his company's exhibit of oxygen generators.

WHIMSY COEFFICIENT HIGH AT SWAMPSCOTT

THE secret organization known as the "Republican and the New Deal Athletic and Debating Society" took charge of the A.I.Ch.E. regional meeting last month at Swampscott, Mass. The results were vastly entertaining, reaching a climax on Tuesday evening at a barn-dance attended by almost all at the meeting. The original members of the secret society, made known their identity via a badge of bearded codfish rampant with a Kelly green label pendant proclaiming the wearer "an original Ichthyologist," one of the dozen chemical engineers who had, with humor and good fellowship, begun in 1931 the Boston Section of the A.I.Ch.E. Most of the original twelve who founded the group were present at a Ichthyologists' luncheon Tuesday noon at which the President of the Institute Warren McCabe, and all future presidents of the Institute, were elected a member of the Boston Local Section with the title, "Honorary Poor Fish." This is in line with the philosophy of the present by-laws which specify members as Fish, and officers as Kingfish, Mackerel, Smelt and Shark.

The original by-laws of the secret society were distributed and proved to be even more informal—specifying three classes of members, Economic Royalists, Forgotten Men and Honorary, the latter membership good only for six months and attained by purchasing of one round of refreshments for all members present at a meeting. Other rules of this unique constitution provided for a fiscal year which "shall start Oct. 7, which is Harvey Skinner's birthday," and "In case of the absence of the President the duties of his office shall fall on Jack Healy who is good-natured and won't mind."

Still good-natured, Jack Healy, as chairman of the committee on arrangements, benignly ran a huge, smoothly operating committee which housed, registered and otherwise provided for the 616 who turned out for the regional meeting.

Officially the meeting was opened by Gustavus J. Esselen in an address of welcome on Monday morning. He called attention to the fact that chemical industry was an important part of the commercial life in the New England area. He said that 549 chemical plants were in operation there before World War II, employing 12,000 workers and adding to the value of the products made some 58 million dollars. Today there are 681 plants in the same district, with 28,000 employees, and an added valuation of 141 million dollars. This represents an increase through the war years of 141 per cent. Historically, said Dr. Esselen, the Swampscott area is important to the chemical industry. The first tannery in the U. S. was opened in 1631, less than a mile from the site of the meeting hotel, and two years later, salt manufacture was started in Beverly. In 1700 the potash industry of Colonial times began at Ashburnham, the town name being descriptive of the process, and production finally reached a ton a day.

At luncheon on Monday, Dr. Alfred P. Neal, vice-president and director of research of the Federal Reserve Bank of Boston, addressed the members on the prospects for a steel plant in New England. The prospects, as developed by the speaker were extremely favorable. Dr. Neal pointed out that present fuel efficiencies in steel plants are making a relocation of processing plants possible. A century ago, he said, five tons of coal were required for a ton of steel, and it was cheaper to move the two or three tons of ore to the coal, and then ship the pig iron or steel to the market. Now however, he said, the trend is toward locating the steel plant nearer to markets, rather than to coal supplies. This is largely due, he continued, because of fuel economics. In place of five tons of coal for a ton of finished steel, a modern mill using a heavy scrap charge would require only 1876 pounds of coal. Use of scrap is one of the reasons for such a saving he pointed out, and a good reason for moving a modern steel mill to the market is because the scrap is generated there.

According to his estimate, the economist stated, a modern integrated mill in a New England location would require for a ton of steel 0.938 tons of coal, 1.4 tons of ore and 0.825 tons of scrap. Adding to the above reasons favoring a New England mill, he argued that other changes are imminent: coking coals in West Pennsylvania and East Ohio are being exhausted, with better grades available at a distance in West Virginia and Kentucky; the high-grade shipping iron ore of Minnesota is

being exhausted, with only 12 to 15 years' supply at present consumption rates; new discoveries of high grade iron ore have been made in Labrador and Venezuela. This all leads to one conclusion he claimed, New England is advantageously located to assemble the raw materials for making steel. The points in favor of this were as follows: The area has an advantage in distance as far as the Labrador ores were concerned, and the distance from Palus, Venezuela, to New London, Conn., by boat 2232 miles and to Trenton, N. J., the distance was 2225. (Trenton is now being considered as the site of a new steel plant.) The slight disadvantage in the cost of coal, which would be about the same for the Chicago area would be offset by pressurizing of the blast furnace, a shorter ore haul, cheaper ore and cheaper scrap. This last item would amount to about $2.00 per ton of steel. In addition, New England enjoys about the lowest-priced limestone in the country, in Dr. Neal's opinion.

One of the points touched on was the potential market in New England for steel. According to the analysis presented, it amounts to 3½ million tons of sheet, strip and bars. It was also shown that the metal-working industries are the fastest growing in New England, the area does not yet make its share of automobiles, parts, refrigerators, etc., and these industries may be expected to grow in time.

The speaker concluded with the thought that while the idea may seem at first glimpse to be far-fetched, it was far enough along in backing so that such a mill could be expected in the area in the predictable near future.

A.I.Ch.E. Reaches 10,000 Mark

At this same luncheon, Warren L. McCabe, the A.I.Ch.E. President, announced that the Institute had passed an important milestone in its growth, it had passed the 10,000 mark in membership growth. For the occasion he read a telegram from the 10,000 member, Lewis C. Hullinger, chemical engineer with the Standard Oil Company of Indiana. Hullinger, a graduate of Ohio State University in 1947, who has been with the company since his graduation called attention to the fact, in his telegram, that the steady growth of the Institute was proof of the place of chemical engineers in industry.

At the technical meeting, Monday afternoon, psychological testing of engineers, a subject of round tables at the Institute meeting in Tulsa and French Lick last year, came in for more discussion. Arthur L. Miller and Paul C. Miller of Miller Associates of Boston reported on some of their experiences in giving such tests.

Psychological tests can pick the good prospects for engineering jobs from the poor ones and can guide an engineer into the right kind of job for his own aptitudes, the two men said.

For the record, since time has a habit of adding infinite variety, the Editor has been asked to list in this report of the Swampscott meeting the names of the original group who formed the Ichthyologists in 1931. They are:

F. W. Adams	**A. L. Gardner**
F. S. Bacon	**A. D. Little***
Osborne Bezanson	**L. A. Pratt**
F. J. Curtis	**W. P. Ryan***
D. S. Dinsmoor	**H. J. Skinner**
G. J. Esselen	**R. S. Weston***

*** Deceased**

After outlining seven types of ability needed by the engineer they continued, "Of course, not all engineers possess large amounts of all seven types of ability. However, it is important to recognize that not all engineering jobs require all seven abilities. Some jobs are well filled by a 'slide-rule technician'; other jobs require a top-flight engineer." No single test is satisfactory for determining an engineer's capacity, but a carefully designed combination of several tests have given highly profitable results.

The authors reviewed the kinds of tests now in use, saying that tests of skill with the hands are highly developed and quite accurate but that manual dexterity is of so little importance to engineers today that these tests are seldom used.

More important is the ability to visualize spatial relationships, for which well-developed tests are available. Mathematical ability is important, too, and a variety of tests is available, depending on whether speed of thinking or complexity of thinking is more important.

The ability to handle problems independently is important for engineers who deal with research problems; it is only recently that practical tests of high level ability to think abstractly have come into use. Beyond the ability to handle problems independently is the ability to create new theories and laws, pioneering in unexplored phases of engineering. Tests for this ability in other fields have been developed but are not widely used in selection of engineers.

A special problem is the selection of good administrators from among engineers. This is a simple matter for the psychologists, who have plenty of tests for administrators and can apply them in conjunction with the other engineering tests.

The speakers listed four reasons why young men go into engineering. One is that a scientific and engineering curiosity is awakened at an early age, so much so that the boy engages in experiments on his own. Other boys identify themselves with engineering or scientific heroes, such as Thomas Edison or Steinmetz. The third group is sent to engineering school by the advice of parents, teachers, or others and a fourth group feels that engineering is a good place to get a job. The best engineers are usually those for whom awakened scientific curiosity is followed by identification with a hero and the benefits of good guidance.

The boy who is not naturally curious cannot expect much stimulation from any technical school, the speakers said, adding that in both engineering and business education "it is possible to go through college and make high marks by using only rules and formulae. Too often engineering students have been prepared for college by being drilled in the application of rules and formulae of science and engineering rather than having been taught how to do some first-hand thinking along with the rules and formulae. Once in college, there is often no personal experience with conjecture, the making of hypotheses or theorizing, and only a memory contact with principles and laws for the purposes of passing quizzes and term examinations or quoting them in a 'slide-rule level' paper."

U. S. potash reserves will last a hundred years even at the present rate of consumption, according to N. C. White and C. A. Arend, Jr., of the International Minerals and Chemical Corp., speakers on the technical program. This vital fertilizer ingredient was so scarce during World War I that it had to be recovered from seaweed and smokestack gases, but discovery and development of deposits near Carlsbad, New Mexico, prevented another shortage in World War II. The engineers reviewed the mining and refining of the potash ore by the three companies now operating in the Carlsbad area, and pointed out the excellent working conditions possible in mining potash ore. The entire underground mine is clean, dry, well ventilated and lighted, with ample headroom. The temperature is even the year round at about 75° F and the colorings of the ore make the mine galleries a beautiful sight they said. The mining itself is highly mechanized, with the ore, broken by blasting, loaded by conveyors into electrically powered shuttle cars.

Editor's Note: The deadlines for this issue came so close to the Swampscott meeting that the full story and all the meeting pictures could not be printed in this issue. See next month's news section.

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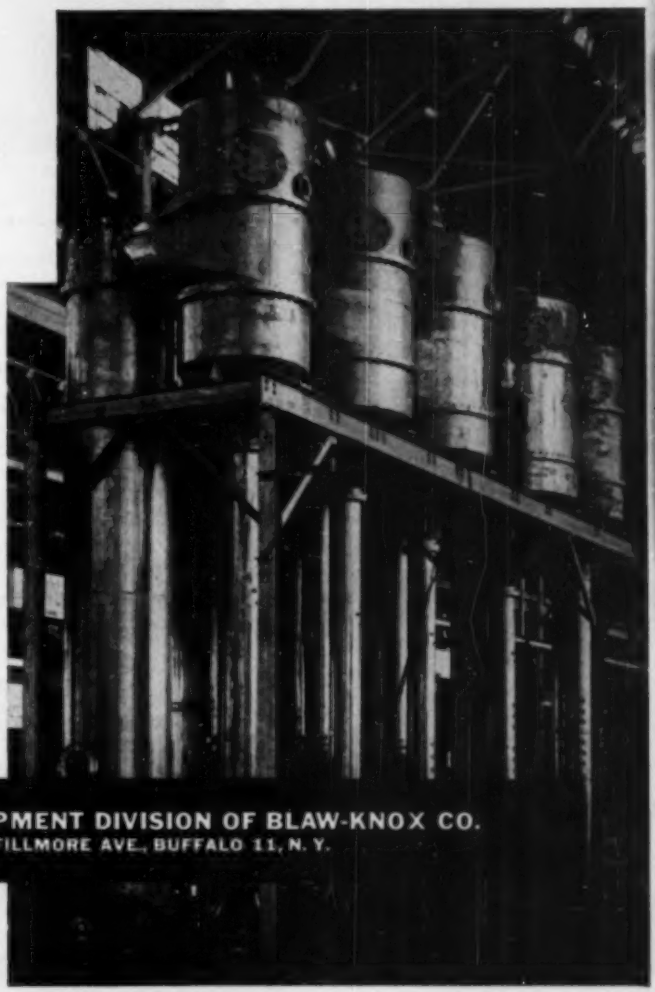

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MONOBED DEIONIZATION

ENGINEERS in the water treatment and process industries are exploring a new idea in deionization, developed by The Resinous Products Division of Rohm & Haas Co., Philadelphia, Pa., which promises to bring major changes to design and operating procedures.

It is the Monobed technique, in which cation and anion exchange resins are mixed intimately in the same bed, the solutions to be deionized or demineralized are passed through, and after exhaustion, the resins are separated hydraulically and then regenerated in the same unit in which the exchange takes place. Heretofore, deionization required the passage of the liquid to be treated through a series of separate beds of exchange material, with regeneration being carried out in these separate units.

Already several engineering firms in the water conditioning field have worked out the design problems of backwashing, regeneration, and mixing of the resins, and have built exchange units as large as 4 ft. in diameter.

After exhaustion of the resins, the intimate mixture is hydraulically separated, since the anion exchanger is lighter than the cation exchanger. Then the anion exchanger is regenerated by sodium hydroxide or other alkali and rinsed. The cation exchanger is next regenerated by sulfuric acid introduced by means of a distributor located at the boundary between the two resin zones. After another rinsing, the resins are remixed by air from jets at the bottom of the bed.

Advantages of the new method over conventional 2-bed deionization according to Rohm & Haas spokesmen are lower cost of operation, lower cost of equipment, ease of operation, controlled quality of effluent, lower rinse requirements, uniform performance in intermittent service, sharp break-through of ionic solids at endpoint, relative independence of quality of effluent from concentration of influent and level of regeneration, maintenance of a relatively neutral pH during deionization.

Rohm & Haas plans to develop six Monobed combinations, some of which it recognizes as potentially more useful than others. Initially, the new concept was developed specifically for applications requiring water of extremely high quality for such uses as the deposition of television phosphors, the dilution of hydrogen peroxide, etc. A combination of Amberlite *IRA*-400, a strongly basic anion exchanger, and Amberlite *IR*-120, a strongly acidic cation exchanger, is used in the first Monobed. Water

(*Continued on page 20*)

Problem: How to protect tanks at atmospheric pressure from fires

THE

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Combination Vent Valve—

FLAME ARRESTOR Isolates Inflammable Materials from Fire

Note the tanks in the lower left of the above fire scene photograph. These tanks and valued contents were saved because they were equipped with BS&B Vent Valve FLAME ARRESTORS. The device acts instantly to eliminate tank fires.

The BS&B Vent Valve FLAME ARRESTOR, may enable you to receive a reduced insurance rate. It will pay you to investigate.

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FREE CATALOG FOR YOU

This new BS&B Catalog for the Chemical Industry will give you the complete story on Vent Valve-Flame Arresters and acquaint you with many other BS&B products designed to give you extra protection for your property and to safeguard the lives of your personnel.

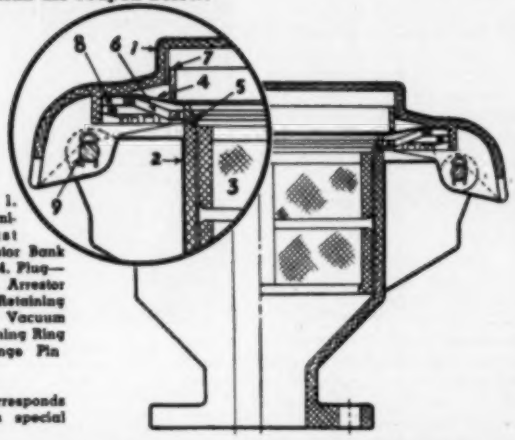
Solution: COMBINATION VENT VALVE

BS&B flame arrestor

The BS&B FLAME ARRESTOR is a neat, compact unit which becomes an integral part of the BS&B VVFA Vent Valve. It adds the advantage of fire control. The Arrestor bank prevents propagation of flame into your tank. Valve is designed to function under internal pressure or vacuum. Any volatile material held in tank storage without proper protection is a potential bomb.

Flame cannot penetrate the honey-combed construction of the all aluminum BS&B FLAME ARRESTOR bank. The BS&B Vent Valve FLAME ARRESTOR operates automatically and requires no hand snuffing or manual attention. It is quickly removed . . . for cleaning or replacement.

Chemical plant executives, engineers and superintendents are especially invited to investigate the new BS&B Vent Valve FLAME ARRESTORS. We will be glad to show the proven protection these units give. There is no cost or obligation . . . just mail the coupon below.



SPECIFICATIONS: 1. Cover—Cast Aluminum. 2. Body—Cast Iron. 3. Flame Arrestor Bank—Rolled Aluminum. 4. Plug—Synthetic Rubber. 5. Arrestor Spring—Steel. 6. Retaining Ring—Aluminum. 7. Vacuum Ring—Steel. 8. Retaining Ring Spring—Steel. 9. Hinge Pin—Stainless Steel.

NOTE: Bolt circle corresponds to 150 ASA unless special drilling specified.

Pressure-Vacuum Vent Valve Flame Arrestor 2, 3, 4, and 6 inch sizes; internal opening pressure (ounces) minimum 0.5, maximum 1.75, and vacuum opening (ounces), 0.5. **Pressure-Vacuum VVH Vent Valve** (Does not include Arrestor bank) Used as secondary relief valve or, as primary relief valve where Arrestor bank is not required.

Valve Inch Size	Opening Pressure Ounces		Vacuum Opening Ounces
	Minimum	Maximum	
2	3.5	16	0.5
3	3.5	16	0.5
4	2.5	16	0.5
6	2.5	16	0.5
8	2.0	16	0.5
10	2.0	16	0.5
12	2.0	10	0.5
16	2.0	8	0.5
20	2.0	6	0.5
24	1.5	4	0.5

NOTE: Pressures in this table are for cast aluminum cover, and they will differ from other metals. Pressure ratings require a manufacturing tolerance of plus or minus 5 per cent. Vacuum opening can be increased.

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STERLING DRUG CENTRALIZES RESEARCH AT RENSSELAER

The new $4,000,000 research center of Sterling Drug, Inc., the Sterling Winthrop Research Institute, was formally dedicated at Rensselaer, N. Y., in ceremonies on May 17-18. The Sterling Winthrop Research Institute will serve all units of Sterling Drug, Inc., and will provide complete facilities for research in organic chemistry, biochemistry, pharmacology, virology and other branches of medical science. A pilot plant of glass-lined and stainless steel equipment with still-kettles of 5- and 50-gal. capacity is available for developing production methods to be used in full-scale manufacturing processes.

PROCEEDINGS AVAILABLE FOR GENERAL PURCHASE

The Proceedings of the First National Air Pollution Symposium, Nov. 10 and 11, 1949, Pasadena, Calif., sponsored by Stanford Research Institute in cooperation with California Institute of Technology, University of California and University of Southern California, are now available.

Proceedings of the Second Annual Northern California Research Conference, Jan. 11, 1950, San Francisco, Calif., sponsored by San Francisco Chamber of Commerce, University of California, Stanford University and Stanford Research Institute, are also available.

The two sets of proceedings were published April 1, 1950. Following distribution to the subscribing members the published proceedings are now available for general purchase. Orders may be placed immediately with the public relations office, Stanford Research Institute, Stanford, Calif. Proceedings of the First National Air Pollution Symposium covering 149 pages cost $2.50. Proceedings of the Conference cover 66 pages and are priced at $2.00.

SILLIMAN CHAIR IN CHEMISTRY FOR CARNEGIE

A new professorship in chemistry has been established at Carnegie Institute of Technology through a grant by the Gulf Oil Corp., according to a joint announcement by Robert E. Doherty, president of Carnegie, and Sidney A. Swensrud, president of Gulf.

The new chair, supported by a grant of $15,000 per year, will be held by Dr. Frederick D. Rossini, currently chief of the thermochemistry and hydrocarbons section of the National Bureau of Standards and recently appointed head of Carnegie's chemistry department. Dr. Rossini, a Carnegie alumnus and A.I.Ch.E. member, will join the faculty on July 1.

In the announcement, President Doherty said that the new chair will be named for Benjamin Silliman, who was one of the country's most distinguished scientists during the 1800's and a pioneer in the chemistry of petroleum refining.

MONOBED DEIONIZATION

(Continued from page 18)

whose electrical resistance is 15,000,000 ohms per centimeter can be prepared by passing raw water through this mixture, designated Amberlite *MB*-1. Apparently, the resins intimately mixed are analagous to an infinite number of alternate cation and anion exchanging units. The result is elimination of leakage (minimized in conventional deionization by using four or more alternating units).

MB-2 is the combination now being developed most extensively. It is a mixture of Amberlite *IRA*-410, a new, strongly basic anion exchanger, and Amberlite *IR*-120. It is expected that this combination, which produces water of somewhat lower quality than that produced by *MB*-1 will be used for preparing feed water for high-pressure boilers, where silica must be removed.

MB-3 is a dyed version of *MB*-2 destined to be used by the ultimate consumer of small quantities of deionized water. Its blue color turns to brown as the resin becomes exhausted.

The fourth combination, *MB*-4, makes use of *IR*-120 and *IR*-45, a new, weak-base anion exchanger. This combination will find use in preparing water for boilers which will tolerate silica, not removed by the weak-base component of the mixture. Sodium carbonate or ammonia can be used to regenerate the anion exchanger in *MB*-4.

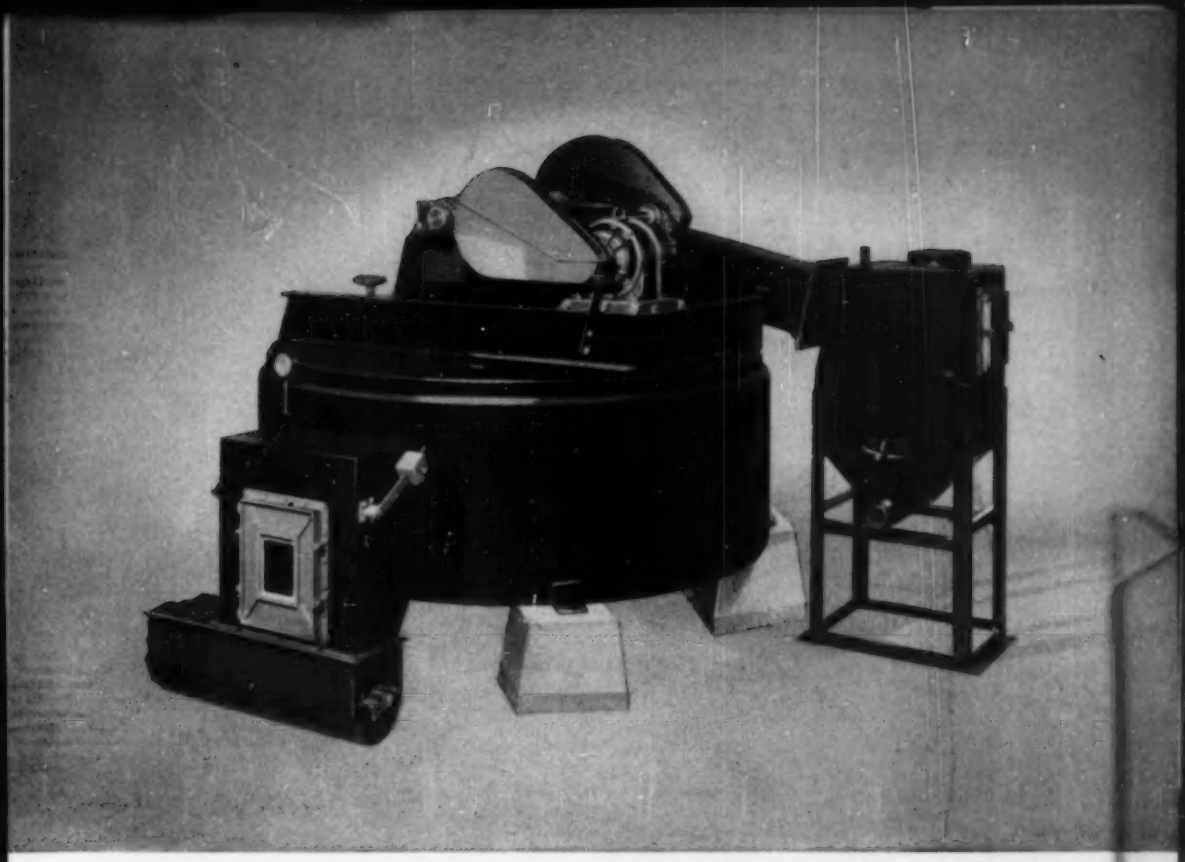
In special applications where acid- or base-sensitive materials are processed, *MB*-5 will be used. Composed of *IRA*-410 and *IRC*-50, a weak acid exchanger, it will operate at a pH of 7 or above in the deionization of whey, rubber latices, or sugar solutions.

The final combination, *MB*-6, will make use of weak acid exchanger *IRC*-50 and weak base *IR*-45. Because it can be regenerated at nearly 100 per cent efficiency, it may prove to be the economical answer to the partial deionization of brackish waters or the treatment of industrial mineral wastes.

PERMANENT MAGNET-TYPE MICROSCOPE OF R. C. A.

This first permanent magnet-type electron microscope was shown last month by the Radio Corporation of America. The new model, much reduced in size over other models is only 30 in. high, and will cost about $6000. A magnification up to 6000 diameters is possible. The unit has a 50,000-volt potential, the same as the larger models. A feature is the introduction of permanent magnets to energize the magnetic fields that focus the beam of electrons used in place of light. Control unit at right provides readings of vacuum and electrical values.

(More Industrial News on page 27)



Standard steam jacketed batch dryers

BARTLETT-SNOW STEAM JACKETED BATCH DRYERS are ideally used for drying small lots of various chemical salts, wood flour, tankage and similar materials.

Standard low cost style A dryers consist of a short vertical cylinder about 30 inches high with flat top and bottom. The top is closed, and is provided with a vapor outlet fan and charging door. The sides and bottom are steam jacketed in accordance with A.S.M.E. codes for steam pressures up to 100 p.s.i. in the jacket and 15 lbs. vacuum in the vessel. A two-armed cast steel sweep, keyed to the bottom of a center shaft, agitates the charge to prevent localized overheating and discharges the material through a door in the side after drying has been completed. Power requirement ranges from 5 to 15 HP depending upon the size and weight of the batch. Standard drive arrangements include; tight pulley, silent chain, V-belt or a heavy duty four speed transmission. Three standard sizes, with drying chambers 6', 8', and 10' in diameter, and capacities of about 1200, 3000, and 6000 pounds per charge, can usually be shipped promptly.

Send for a copy of Bulletin No. 89. It describes the scope of our service in detail, and let the Bartlett-Snow heat processing engineers work with you on your next drying, cooling, or calcining problem. The C. O. Bartlett & Snow Company, Cleveland 5, Ohio. Engineering representatives in New York, Baltimore, Detroit and Chicago.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Frayed Third Thread

The Autobiography of Robert A. Millikan. Prentice-Hall, Inc., New York. (1950) 311 pp. $4.50.

Reviewed by James G. Vail, Vice-President, Philadelphia Quartz Co., Philadelphia, Pa.

THREE main threads in this volume deserve the attention of scientific men. It is well written, replete with anecdote and its story of the full and active life of an exceptionally able man is good reading.

The personal success of a boy born to pioneer parents in 1868, though not without parallel in American history, is full of human interest. Robert Millikan's endowment consisted of good health, mental vigor and an urge to push out the frontiers. It sustained great labors which brought him recognition as a teacher, writer, investigator and participant in the development of two of our foremost institutions of higher learning. As a man of action, he achieved great responsibilities and great recognition. The disciplines involved command universal respect. Told with modesty and touched here and there with the spark of humor, it is a stimulating human document.

The second thread is the rise of modern physics. Here one meets, as living personalities, nearly all the men of memorable name and sees the fundamental contribution of his own research in course of evolution. The chapter "My Oil-Drop Adventure (e)" is a lucid and thrilling account of the processes by which he demonstrated for the first time the unitary nature of electrons and counted them "with exactly as much certainty as he can attain in counting his fingers or his toes." This was a principal contribution cited in the award of the Nobel Prize in 1923. The interplay of work and discussion which has carried physics to its present high development within the span of a single human life as seen through the eyes of one of the principal actors is a drama which alone makes the account worth reading.

About a third of the book deals with extracurricular activities. He has a keen eye for the sinister influences which have eventuated in two world wars and threaten a new cataclysm of incredibly greater import for the human race. His formula for meeting the situation is more and greater power. His personal religion leads him to speak of "world loyalty" and the sacrifice of life itself for the common good. He sees no conflict between science and religion, with which most of us can agree, but the pacifism of Jesus and Gandhi he regards as impractical. The dilemma of an ideal of personal morality and corporate violence seems to leave him undisturbed. His belief that atomic weapons are the greatest contribution to a peaceful world makes this reviewer doubt his competence to read history or understand the urgency of new techniques in human relationships. The fear argument has been used in support of every major military invention.

As philosopher and man of religion, one has the feeling that creative imagination such as that which characterizes his scientific work is lacking. His supreme right to speak as a scientist does not confer equal authority in other areas, even when his views are stated with equal assurance.

Thoughtful readers will still be looking eagerly for leadership toward a moral world as bold and original as that which abandoned obsolete concepts of the atom.

For the Nuclear Physicist

Trilinear Chart of Nuclear Species. William H. Sullivan. John Wiley & Sons, Inc., New York 16, N. Y. 1st Edition (1949) $2.50.

Reviewed by John R. Huffman, Argonne National Laboratory, Chicago 80, Ill.

THE Trilinear Chart of Nuclear Species, when properly assembled, presents on a single panel the systematics of and physical-constants data for all experimentally identified nuclear species known from information available in June of 1949. Each isotope, either natural or artificial, of every element appears on the chart.

The trilinear coordinate grid has been developed from a rectangular plot, having A-Z (number of neutrons) as the ordinate and Z (atomic number) as the abscissa by compressing the ordinate-abscissa angle to 60°, then rotating the entire graph clockwise 30°. On this triangular plot each single nuclear species is represented by a hexagon. By this method a simultaneous plot, with equal emphasis, of A vs. Z, A-Z vs. Z and A-Z vs. A is obtained.

By means of various background and insert colors, use of black or white numerals in the hexagons and other symbols, considerable information on each species is presented. These data include: relative abundance of isotopes, atomic mass, angular momentum, magnetic dipole, slow neutron cross sections, half-life, modes of disintegration, branching ratios, energy of radiation, modes of production and genetic relationships. The majority of the known nuclides are radioisotopes, artificially produced by particle bombardment or through the resulting decay chains.

For scientists and engineers concerned directly with nuclear physics, nuclear chemistry, and radioactivity these charts will be of value. For easy use they require some study in order for one to become familiar with their form and contents. Data for many of the nuclides will be outdated in a short time due to fairly active experimental work in these fields.

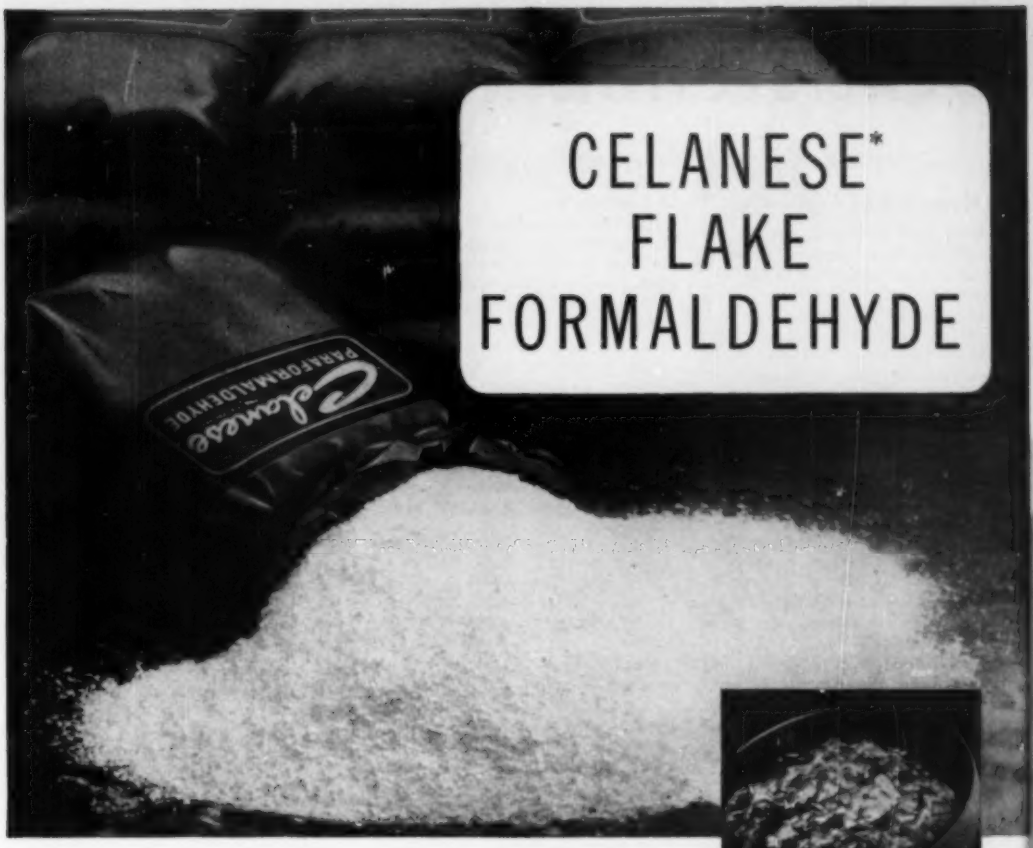
Persons interested in normal chemical and engineering fields will find little of technical value. For them the charts contain much data which are seldom required.

Books Recently Published

Germany 1947-1949 — The Story in Documents. Department of State Publication 3556, European and British Commonwealth Series 9. Division of Publications. U. S. Government Printing Office, Washington 25, D. C. (1950). 632 pp. $3.25.

This compilation was prepared by Velma Hastings Cassidy, of the Division of Historical Policy Research, Office of Public Affairs, with the collaboration of the Bureau of German Affairs.

Biological Studies with Polonium, Radium, and Plutonium. National Nuclear Energy Series VI-3. Editor Robert M. Fink. McGraw-Hill Book Co., New York (1950) 412 pp. $3.75.



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LOCAL SECTION NEWS

SYMPOSIUM

Marketing New Products

A symposium on the Development and Marketing of New Chemical Products was held in Cleveland, Ohio, at the Hotel Hollenden, April 14, 1950. It was sponsored by the Cleveland, Ohio Valley, Detroit, Pittsburgh, Central Ohio and Akron Sections of A. I. Ch. E. and was attended by about 200 people. In addition to delegates from these sections a large group came from Toledo.

Consonant with the subject of the symposium the problems discussed were along the lines of the ability to market products of chemical and allied industries.

A "Welcome to Cleveland" was delivered by R. L. Savage, Symposium Chairman, with introductory remarks by J. H. Koffolt. A luncheon talk, "Who, What and Why of Selling," was given by Frank A. Kolb.

All papers presented at the meeting were listed in the March issue of C. E. P., p. 34. Preprints of the papers are available at $1.00 for the complete book. Requests should be sent to:

Dr. R. L. Savage
Case Institute of Technology
University Circle
Cleveland 6, Ohio.

Reported by J. R. Crosby

SOUTH TEXAS

A meeting was held April 21, San Jacinto Day, at the Texas A. and M. at College Station, Tex. The first event on the program was a conducted tour through the teaching and research facilities of the chemical engineering department at Texas A. and M. and through the Memorial Student Center of Texas A. and M. now nearing completion on the campus.

The speaker for the meeting was M. H. Leavenworth, manager of the Dallas office of Dow Corning Corp., who gave a demonstration talk on "Silicones at Work in Industry."

At the conclusion of the technical program the group adjourned to the home of Dr. J. D. Lindsay, head of the department of chemical engineering at Texas A. and M. and past chairman of the section, for a social hour and barbecue dinner. A feature of the social hour was a musical program by a western instrumental quartet comprised of members of the Texas A. and M. chemical engineering staff.

Reported by G. T. McBride, Jr.

WESTERN NEW YORK

Dr. J. H. Rushton, director of chemical engineering at Illinois Institute of Technology and director of research for Mixing Equipment Co., addressed this section on April 20 at the Hotel Sheraton in Buffalo. Dr. Rushton discussed the factors influencing the mixing of liquids, solids and gases with liquids. Motion pictures and slides were used to illustrate flow patterns.

The election of officers for the coming year resulted in the following selections:

Chairman.....Arthur Cerda
Vice-Chmn.....Earl Mirus
Secy.-Treas.....James Troyan
Directors:
John J. Rieck, William Mitchell, Noah Davis
Technical Societies
(Council Rep.).....Matt Weber

Reported by Earl C. Mirus

OHIO VALLEY

At its annual meeting on May 1, 1950, this section elected the following officers for the 1950-51 term, beginning in September, 1950:

Chairman—Alex C. Brown, Emery Industries, Inc.
Vice-Chmn.—Raphael Katzen, Vulcan Copper & Supply Co.
Treas.—Theodore B. Wiehe, Schenley International
Secy.—Arthur C. Greber, Schenley Distillers, Inc.

Following the business meeting, two papers were delivered by students of the University of Cincinnati. William F. Pansing of the Graduate School spoke on "Solvent Extraction, Mechanism of Solute Transfer." A paper on the "Design of a Chromium Waste Disposal Process" was delivered by William B. Taylor, a senior student in the chemical engineering department.

Reported by A. C. Greber

NEW ORLEANS

The Louisiana Council of Engineers met in New Orleans April 3 to reconsider the Professional Engineers Registration Law. Representatives were present from this section and from many engineering societies. The two most important points were in the definition of professional engineering and in the experience requirements—none being required after graduation. The original draft of the bill passed by the legislature in 1948 conformed to the experience requirements of the Model Law but this was changed by the legislature itself. It was voted unanimously to introduce the same version of the bill that was passed in 1948.

Reported by R. M. Persell

SPEAKERS OF MARKETING SYMPOSIUM HELD IN CLEVELAND APRIL 14

Morning program, left to right: F. O. Calhoon, Disco Co.; G. Thiessen, Koppers Co., Inc.; W. D. McElroy, Pittsburgh Consolidation Coal Co., R. D. Aylesworth, Emery Industries, Inc.

Afternoon program, left to right: H. J. Barrett, Du Pont Co.; J. F. Foster, Battelle Memorial Institute, H. E. Balz, Glass Fibers, Inc.

DETROIT JUNIOR GROUP

The Detroit Junior Group met May 2 and heard Dr. E. C. Pattee, consulting engineer, discuss "Waste Disposal." Dr. Pattee stated that, in general, an industry has three alternatives to consider when faced with a disposal problem. These are: (1) investigation of the process to see if the problem can be eliminated or minimized by a change in the process, (2) recovery of the waste for use in a second process, and (3) the actual satisfactory disposal of the waste. In many cases the former two alternatives have actually proved profitable to the industry and several examples were cited by Dr. Pattee.

This group met April 4 and heard R. G. Angle speak on "Problems in Automotive Finishes." Mr. Angle of the Du Pont Co., discussed first the basic formulae for lacquers and synthetic enamels, then the usual method of application, and finally the problems occurring both in the plant and in the field.

Reported by P. A. Lenton

EAST TENNESSEE

At the twenty-fifth general meeting held May 2 in the foremen's conference room of the Tennessee Eastman Corp., Kingsport, 26 members were present.

Phillip Frenau, chief engineer of the steam jet ejector department of the Elliott Co., Jeannette, Pa., discussed the characteristic performance curves of steam jet ejectors. He mentioned the design problems involved in getting ejectors of special characteristics; further he stated that with an ejector of known characteristics, the ejector could be used as a meter where other metering equipment is impractical.

Reported by R. H. Morrison, Jr.

COASTAL GEORGIA CHEMICAL ENGINEERING CLUB

An organizational dinner meeting of the chemical engineers in the coastal Georgia section was held April 28 in Savannah. In attendance were approximately 35 persons from Savannah, 13 from Brunswick, and four from Charleston, S. C.

E. P. Tait of Alloy Steel Products Co. gave a talk on corrosion in the chemical industry.

Following Mr. Tait's speech a short business meeting was held at which J. R. Lientz, general superintendent of the pulp and paper division, Union Bag and Paper Corp., acted as chairman.

Reported by E. O. Barnes

(*More Local Section News on page 33*)

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CANDIDATES FOR MEMBERSHIP IN A.I.Ch.E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *July 15, 1950*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

James L. Baird, *Waltham, Mass.*
M. E. Barker, *Fayetteville, Ark.*
Jack R. Caddell, *Wilmington, Del.*
Frank E. Caddy, *Houston, Tex.*
R. M. Camp, *Associated, Calif.*
Fred B. Crist, *Chicago, Ill.*
T. W. Dalton, *Collinsville, Ill.*
John F. Frank, Jr., *Charleston, W. Va.*
James S. Gilliam, *Stamps, Ark.*
J. A. Grant, *Newark, Ohio.*
P. N. Hall, *Midland, Mich.*
David W. Hengerer, *Niagra Falls, N. Y.*
Charles R. Holman, *Milwaukee, Wis.*
Leo Leonhard Holzenthal, *New Orleans, La.*
William G. Hughes, *Plainfield, N. J.*
James G. Hunter, *Homewood, Ill.*
John H. Johnsen, *Hammond, Ind.*
William B. Katz, *Chicago, Ill.*
L. B. Kuhn, *Pottstown, Pa.*
Sidney Kuniansky, *Falls Church, Va.*
Richard M. McGhee, *Terre Haute, Ind.*
Ernest O. Ohsol, *Pittsfield, Mass.*
Rudolph J. Ozol, *Union, N. J.*
Paul J. Peltier, *Wilmington, Del.*
Fred H. Poettmann, *Bartlesville, Okla.*
L. G. Rodgers, *Tulsa, Okla.*
Paul W. Saunders, *St. Albans, W. Va.*
James H. Schmitt, *Charleston, W. Va.*
Robert F. Schultz, *Niagara Falls, N. Y.*
W. H. Tenn, Jr., *Houston, Tex.*
John H. Wardwell, *Midland, Mich.*
Wm. H. Weed, *Baltimore, Md.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Carl M. Aikele, *Houghton, Mich.*
Julius T. Banchero, *Ann Arbor, Mich.*
J. K. Dixon, *Houston, Tex.*
George H. Duckworth, *East St. Louis, Ill.*
Henry H. Gilman, *Rutherford, N. J.*
Leslie E. Herbert, *Baltimore, Md.*
Nathaniel J. Heyward, *Baltimore, Md.*
Charles E. Knox, *Houston, Tex.*
Thomas H. Moore, *Ridgefield Park, N. J.*
Harry F. Tew, *Borger, Tex.*
Elmer M. Thomsen, *Concord, Calif.*

APPLICANTS FOR JUNIOR MEMBERSHIP

James A. Amend, *Waukegan, Ill.*
Harold W. Anway, Jr., *St. Louis, Mo.*
Harry J. Aroyan, *San Pablo, Calif.*
Albert B. Baker, *Freeport, Tex.*
Ralph W. Baker, *Baton Rouge, La.*
James E. Berryman, *Dallas, Tex.*
John Blickman, *Harvey, La.*
R. L. Booth, *Tacoma, Wash.*
Henry C. Bramer, *Pittsburgh, Pa.*
Rufus C. Brock, *Rome, Ga.*
Earl W. Brockman, *Lansing, Ill.*
John W. Brunk, *Baltimore, Md.*
Thomas S. Burns, *Savannah, Ga.*
A. G. Clark, Jr., *Gary, Ind.*
Robert G. Craig, *Wilmington, Del.*
John T. Cumming, *Cleveland, Ohio.*
Herbert J. Danne, *Tulsa Okla.*
Tyre H. Dinwiddie, Jr., *Alameda, Calif.*
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Edwin J. Jablonski, *Washington, D. C.*
Kent Jander, *Washington, D. C.*
Wilbur William Kennett, *Eaton Rapids, Mich.*
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Howard E. Woodward, *Kansas City, Kans.*
G. N. Woolnough, *Montreal, Que.*
Chester V. Zabielski, *Schenectady, N. Y.*
W. F. Zimmermann, *Texas City, Tex.*

INDUSTRIAL NEWS

(*Continued from page 20*)

LUMMUS CO.'S "PETROLEUM HORIZONS" AVAILABLE

An 80-page manual covering petroleum refining, petroleum chemical and chemical manufacturing activities, has been prepared by The Lummus Co., New York, and dedicated to all the executives, technicians and workers in offices and plants who "have made the refining and processing of petroleum and the production of chemicals great industries which Lummus is proud to serve."

The story of petroleum—from crude to products—and of the Lummus Co.'s vital role in this progression is unfolded within these pages and enhanced by 31 two-color flow diagrams of petroleum refining and petroleum chemical processes including typical operating data, and 75 four-color photographs of process units, as well as bar charts, drawings, etc. Accompanying informative text discusses technical, economic and other phases of each process.

A free copy of Petroleum Horizons will be sent to anyone requesting it. Letters should be directed to the company at 385 Madison Avenue, New York 17, N. Y.

SEWAGE FACILITIES OF U. S. SUMMARIZED

"Statistical Summary of Sewage Works in the United States," which is based on the 1945 Inventory of Water and Sewage Facilities in the United States, was recently published as Supplement 213 to Public Health Reports. This report, presenting a complete summary of sewage works practice, is designed to furnish summarized data on various phases of sewage practice, and to serve as a record from which trends may be developed in future years.

Prepared by John R. Thoman, sanitary engineer, Environmental Health Center, Cincinnati, Ohio, this 29-page report is divided into two main sections. The first, Basic Data, includes the history of this continuing census, methods for tabulating the information including the estimated population served, type of sewers, ownership, etc.

The second division, Analysis and Interpretation, covers population groups, geographical areas, development of community sewer systems, primary treatment, intermediate and secondary treatment, sludge processing. In all 23 tables implement the text.

Data on which the inventory is based were furnished by the sanitary engineering division of the various state health departments.

The pamphlet, printed by the U. S. Government Printing Office, Washington 25, D. C., is available at 10 cents.

(*More Industrial News on page 30*)

NEWSCAST

PUBLISHED BY THE COOPER ALLOY FOUNDRY CO., HILLSIDE, N. J.

RESEARCH SCIENTISTS FIND NEW RELIEF FOR ALLERGIES

NEW ANTI-HISTAMINE TABLETS NOW PRODUCED BY CIBA PHARMACEUTICAL

Although every tenth person suffers from an allergy, the medical profession is still in the dark as to what makes people allergic. For this reason, research scientists at Ciba Pharmaceutical Products, Inc., Summit, N. J., have been seeking an effective and safe anti-histamine . . . a chemical able to prevent or alleviate sneezing, itching and other effects of various forms of allergy. As a result of this research, Ciba announced in 1946 *Pyribenzamine* . . . a new antihistamine drug that promised not only to revolutionize the treatment, but to throw new light on the complexities of allergy.

Strict hygienic codes necessitated careful selection of processing equipment. Cleanliness, freedom from contamination, reliable service, ease of maintenance, and resistance to corrosive attack had to be considered. Ciba's engineers standardized, among other tested materials, on Monel . . . the nickel-copper alloy rapidly gaining such prominence in chemical and allied fields.

Cooper Alloy MM is specified for all valves, pipes and fittings required to handle corrosive chemicals in certain key stages of processing. Standardization on Cooper Alloy Monel fittings and gate valves has meant trouble-free economical production from the outset. According to Walter Bluntschli, Ciba's distinguished Vice-President, "Certain stages in the manufacture of *Pyribenzamine* demand the use of corrosion resistant Monel gate valves which give uninterrupted service in systems which are both liquid and vacuum tight. Our past experience indicated that Cooper Alloy valves would do the trick, and our present production of highest quality PBZ indicates that our judgment was not in error."

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In Canada: Railway & Power Engineering Corporation, Ltd.

Chemical Engineering Progress

DATA SERVICE

CHEMICALS

1 • PLASTICS. Polythene, nylon, Teflon, Lucite and other plastics of the Du Pont Co. are shown in a polychemicals department bulletin. Describes the forms available and uses, working techniques, properties, etc. A table is shown which gives mechanical, thermal, electrical, optical and miscellaneous properties of all the Du Pont Co. plastics.

2 • HANDLING H_3PO_4. For handling 75% phosphoric acid in tank-car quantities, a new pamphlet of the Monsanto Chemical Co. In addition to specifications for tanks, pumps, pipes, etc., the book gives step-by-step explanations of methods of unloading phosphoric acid cars. Physical properties, corrosion data, (304 stainless steel not recommended), data on rubber-lined tanks, dome fittings, unloading procedures, schematic diagrams, etc.

3 • ALUMINUM STEARATE. Data sheets from Witco Chemical Co. on a new line of aluminum stearate. Data on viscosities in various oils, penetration rates, etc., of greases so made.

4 • SURFACE-ACTIVE AGENTS. From Carbide & Carbon chemical division, a new booklet on Tergitol surface-active agents which shows chemical formula and description of five surface-active agents. Describes uses, test data, physical properties, etc.

5 • TRANSFORMER OIL INHIBITOR. Koppers Co., Inc., has gone into production with a new inhibitor for transformer oils, known as Koppers Improvul 20. Its active ingredient is di-tert-butyl-para-cresol. Data supplied by the company show that uninhibited oils reach a sludging stage in five days or less, and addition of ½% of the inhibitor extended the life of the oil between 19 and 37 days, a 4- to 8-fold increase.

Mail card for more data ▶

6 • CROTONALDEHYDE. A one-page technical data sheet on Crotonaldehyde by Tennessee Eastman Corp., gives specifications, solubility, physical properties, method of shipping. Discusses uses and safety.

7 • GLYCERINE FACTS. A fact sheet issued by the Glycerine Information Service every month, specializes in details of the uses of glycerine. Recent issue covers lubricating jellies, ointments, stopcock lubricants, pigment dispersion to eliminate grinding, etc.

8 • INDUSTRIAL CHEMICALS. The 1950 copy of Eastman industrial chemicals, from Tennessee Eastman Corp. The catalog covers aliphatic, aromatic, inorganic and cellulose products. Physical specifications and other properties are given along with the method of shipping and a brief description of the chemicals uses. Under aliphatic chemicals are such materials as solvents, plasticizers, alcohols, aldehydes, etc. Under aromatic chemicals – phenol ethers, amines, aminophenols, etc.

9 • PLEXIGLAS. Sixteen pages on Plexiglas acrylic plastic molding powders of Rohm & Haas Co. Bulk of the book is given over to photographs of end products, and a two-page table on the average physical properties of Plexiglas.

10 • CAUSTIC. A caustic soda data book from the Mathieson Chemical Corp. covers method of manufacture of caustic soda, its economics, how to unload and handle the material, physical properties of hydroxide solutions, mixing charts, hydrometer conversion tables, etc. Also a section on sampling and analysis.

11 • RADIOACTIVITY CHART. From W. M. Welch Manufacturing Co. a chart drawn by Dr. Herta R. Lang of Rensselaer Polytechnic Institute, which shows the radioactive transformation series of thorium, neptunium, uranium and actinium. Shows change in atomic number, atomic weight, and the emissions that bring about the changes. In color. Large enough for wall mounting.

12 • SOAP ANTIOXIDANT. Pamphlet on the use of ortho biphenyl biguanide for restraining the oxidation of soaps, from Monsanto Chemical Co. Data on characteristics of material, use, economics and test methods.

14 • POLYETHYLENE PRODUCTS. Fibron division, Irvington Varnish & Insulator Co., is now in commercial production on polyethylene film, sheeting and seamless flat tubing. Technical data available.

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BULLETINS

20 • *LOW-PRESSURE VALVES.* A bulletin of The Swartwout Co. on low-pressure regulating valves for controlling the level, pressure or temperature of gases and liquids. Available in most metals. Bulletin also covers pressure controls, details of construction of the controls and valves, and a table giving the weight and dimensions of the available valves. From ½ to 12 in., globe style only.

21 • *MOTORS.* Two pamphlets from U. S. Motors, one on its Unilosed or armored motor, shows cross section of construction, detailed steps on how insulation is built up, and views of various features such as the air-cooling stream, the balancing of the rotors, etc. The second bulletin features the self-lubrication principle of the motors and bearings.

22 • *EQUIPMENT AND CORROSION DATA.* From Nooter Corp., a pictorial story of the fabrication of steel and alloy tanks, pressure vessels, etc. Each page is devoted to some different industry such as chemicals, pharmaceuticals, petroleum processing, food, etc. A 4-page table gives corrosion data for an enormous number of chemicals against 16 different metals.

23 • *RIGID LINE BLIND VALVES.* For installing in lines that are rigid and offer no spreading, Hamer Oil Tool Co. has a new, rigid line, blind valve. A sliding, internal sleeve is moved by a handwheel which releases the spectacle plate so it can be reversed without spreading the pipe line. The booklet, beside giving specifications of valves available, describes the operating principle and advantages.

24 • *STEAM TRAP PROBLEMS.* From The V. D. Anderson Co., a 36-page buyer's guide, reference manual, etc., on steam traps and their problems. Tells where and how a steam trap should be used, and shows via pictures, tables, etc., how they should be installed for various processing equipment. Gives tables for condensation on bare iron and steel pipe, shows how to apply traps to autoclaves, etc. Also has some information on float traps, and air release valves.

25 • *VERTICAL CENTRIFUGAL.* A vertical centrifugal multistage close-coupled process pump of the Peerless Pump division of Food Machinery & Chemical Corp., is described in a 4-page bulletin. Gives construction features of the pump which is suited to pump hydrocarbons, gasoline, propane, etc., hot and cold water, acid bases, etc. Capacities up to 5000 gal./min.; heads up to 1500 ft.

26 • *AUTO-KLEAN FILTER.* Cuno Engineering Corp. has issued a loose-leaf folder of engineering pamphlets on its filters. Explains the construction and operation of filters, which pass the fluid containing solids to be removed between strips of spaced metal, placed edgewise to the flow. Provision made for automatic cleaning and backwash. Other items such as the replaceable cartridge filter, are also shown. Pictures show the installation of various filters which are in such services as filtering paint and varnish dryers prior to drumming, filtering river water for oil refinery service, filtering grease prior to its being packed, etc.

27 • *ALUMINUM PIPE AND FITTINGS.* A well-organized data book from the Aluminum Co. of America on aluminum pipe and fittings, which uses pictures, plus questions and answers, to get across its story. Shows the chemicals that can be piped in aluminum, commodities not normally thought of as chemicals, food and beverage products, etc. In addition lists liquids and gases that cannot be carried in aluminum pipe. Shows how to install, cut, bend, etc. Gives tables of dimensions and weights, chemical properties, collapsing and bursting pressures, loss of head for water flow, etc.

28 • *pH CONTROL.* W. A. Taylor & Co. issue the ninth edition of the well-known "Modern pH Control and Chlorine Control." It is a manual which has sections on the meaning of pH theory, application in industry, as well as a description of the equipment available from Taylor & Co. Contains prices.

29 • *P & T CONTROLLERS.* Mason-Neilan Regulator Co. with a catalog describing a new model pressure and a new model temperature controller. Instruments have a simple, pneumatic proportional controller with narrow-to-intermediate proportional band setting. Gives detail of construction features, plus tables of data on pressure element, element range, and recommended control range.

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Applications and typical schematic drawings indicating correct installation, round out book.

30 • *WIRE BELT PRIMER.* A comprehensive primer on the use of Cambridge wire belts in all industries. The book begins with descriptions of the woven wire, mesh, and other wire belts. Shows all types of belt constructions; gives data on choice of metals; belt specifications; construction of high temperature belts, conveyor design, installation and operation, plus section of pertinent tables: decimal equivalents, conversion of mesh to opening, temperature conversions, openings, strains of materials of various metals and alloys, weights per lineal foot, etc.

31 • *SUPERPRESSURE APPARATUS* Equipment for maintaining pressures up to 100,000 lb./sq.in. and temperatures up to 1000° F., described in American Instrument Co. catalog on superpressure apparatus. Details on various types of high pressure pilot plants; liquefaction of natural gas, manufacture of aviation gasoline, etc. Describes series of superpressure shaking mechanisms, reaction vessels, needle valves, tubes, gas booster pumps, circulators, and all other materials necessary in high pressure work.

32 - 33 • *BALL MILLS AND SIDE-ENTERING MIXERS.* International Engineering, Inc., offers a 4-page pamphlet describing jar mills (**32**) in capacities ranging from 1 to 3 tiers. Construction details are given. (**33**) is a bulletin describing side-entering mixers either as a direct drive or belt or chain drive. Uses, details of packing glands, sizes (½ to 25 hp.), etc., are all given.

34 • *WATERSPHERE.* The watersphere, a water-storage tank, available in capacities from 25 to 250,000 gal., is described in a special bulletin from the Chicago Bridge & Iron Co. For general service and for providing gravity water pressure for fire protection. Built of steel plates, butt-welded, the spherical tank is supported on a single cylindrical column, the flared base of which rests on a concrete foundation. Pipes, ladders, and heating connections are inside the supporting column which rises right through the tank. Painters trolleys, roof, manhole, overflow tube, fence, etc., are all part of the structure.

35 • *COMPRESSED AIR REFERENCE MANUAL.* A basic reference data book on compressed air and gas power is a new publication of the Compressed Air and Gas Institute. Has a general, nontechnical review of the application of compressed air and gas theory to actual machines. Gives uses, outlines air compression equipment used, types of compressors, regulation, indicator card use, etc.

36 • *SOLENOID VALVE.* An air-powered air valve controlled by solenoids is described in a bulletin from The Bellows Co. The valve uses 8-volt solenoids to shift a slide valve which directs the full pressure of the incoming air to shifting the valve. Pamphlet describes other features of the valve, gives schematic wiring diagrams.

37 • *PIPE-LINE THERMOMETER.* For recording temperatures in natural or manufactured gas pipelines, The Bristol Co. describes series 500 recording thermometer. It is equipped with a quick responding extension bulb made of a copper-sensitive stainless steel combination; gives quick response to any temperature change. Instrument, schematic diagram, construction of the temperature-sensitive bulb all shown.

38 • *CRYSTAL DEHYDRATION.* Sharples Corp. in a bulletin on its Super-D-Hydrator, a horizontal, perforated center basket centrifuge, tells of dehydrating techniques on raw materials. The centrifugal is thoroughly described and pictured, operating cycles shown also in colored photographs, through the loading, rinsing, drying and unloading of typical materials.

39 • *PROPANE CYLINDERS.* For those shipping propane in cylinders, a new 4-page bulletin of the Harrisburg Steel Corp. contains interesting data. The cylinders are to I.C.C. specs, 100-lb. capacity, 72-lb. tare weight in aluminum or red oxide ground coats.

40 • *FITTINGS AND PRICES.* An 88-page working catalog of information of Grinnell seamless carbon steel welding fittings and forged steel flanges. Covers all the fittings, elbows, returns, tees, crosses, laterals, caps, saddles, etc. Gives details of features, plus data on all fittings including sizes, prices, etc.

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41 • ***STEAM TRAPS.*** A technical bulletin of types and prices of all Nicholson steam traps. Construction details are shown with cutaway views. Bulletin covers thermostatic traps (industrial, radiator, expansion), weight, and piston-operated traps. Several pages of diagrams show typical operations and recommended piping diagram. Data in the bulletin include methods determining proper sizing, capacities of traps, condensing calculations, etc.

EQUIPMENT

49 • ***PIPE VISE.*** For petroleum and chemical processing maintenance departments, pilot plant work, etc., a new pipe vise of Baker Oil Tools, Inc., may be of interest. Screw-type, open side, will handle tubing, drill-pipe, casing sizes, manifold fittings, valves, etc., from 2⅜ to 8⅝ in. Pamphlet shows recommended mounting. Coarse thread for rapid adjustment.

50 • ***CONTOURED LINERS.*** For lining steel and fibre drum containers, Electronic Wave Products, Inc., is manufacturing polymerized ethylene film shaped in the contours of the tank to be lined. They are offered in a variety of sizes from 5- to 55-gal. capacity. They have a tie-off spout or a semirigid Flexspout and a screw cap. Used for shipping corrosive paste, adhesives, acids, alkalis, etc.

51 • ***CONDUCTIVITY CELL.*** For measuring conductivity of ultra pure demineralized water, Industrial Instruments, Inc., has a new heavy pyrex cell. It uses sheet platinum electrodes and can operate as a continuous flow unit.

52 • ***SAMPLING DIPPER.*** A new sampling dipper of the Harold S. Spencer Co. has a feature which enables the user to transfer liquids to a sample bottle quickly. Made of stainless steel, the dipper can be dismantled and cleaned. The dipper handle, a rod, has at its base a finely ground valve. A movable cup held in place with springs rests on the valve, and when the filled dipper rests on top of the sample bottle, the valve is automatically opened so that the contents discharges through the bottom into the bottle.

53 • ***VACUUM PUMP.*** A new small, (less than 16 in. high) compound vacuum pump of the Kinney Manufacturing Co. is in production. The pump uses an oil-seal pumping system, has an air displacement of 4.9 cu. ft./min., and operates on a 1/3 hp. motor. Vacuum to 0.1μ.

54 • ***HYDRAULIC TEST PUMP.*** For testing boilers, pressure vessels, pipes, etc., up to pressures of 25,000 lb./sq.in., Milton Roy Co. is making a new aiROYmetric hydraulic test pump. Pumps are powered by a simple air cylinder with reciprocating pistons. Air-cylinder diameters are from 2 in. to 14 in., with pump plunger diameters from 5/16 in. to 3½ in. Maximum pressures are obtained by powering small plungers with large air cylinders. Maximum capacities up to 405 gal./hr. Lower pressures are secured by powering larger diameter plungers with large diameter air cylinders. Controls are self-contained trip valves which actuate the air pistons.

55 • ***REFRIGERANT GAS CONDENSER.*** Niagara Blower Co. has a new condenser designed specially for use where Freon is the refrigerant. The condenser is part of a series consisting of five standard units ranging in capacity from 10 to 50 tons refrigeration at 105° F. Freon condensing temperature, and 74° F. atmospheric wet bulb temperature. Operates on the evaporative principle; condensing coils are copper.

56 • ***DIFFERENTIAL PRESSURE TRANSFORMER.*** The Hagan Corp. is manufacturing a new differential pressure transformer for indicating, recording, and controlling the rate of flow of steam, gas, liquid fuel, water, and other materials. Works on compressed air as the power medium, and has been used to measure liquid fuel flow to furnaces in connection with control of fuel air ratio; measurement of liquid level in feed water heaters, condenser wells, tanks, etc.; measures pressure drop across condenser tubes for control of flow; measures steam flow to boilers or flow of water for control or recording purposes.

57 • ***BOTTLE TILTER.*** From the General Scientific Equipment Co., a new 5-gal. bottle tilter, costing $6.25, for pouring liquids to smaller containers. The cradle is made of steel, a chain holds bottle in place while pouring.

58 • ***EXPLOSION-PROOF PROPELLER FANS.*** The ILG Electric Ventilating Co. has new explosion-proof propeller fans for class I, type D hazardous locations. The propeller fan wheel is of aluminum with the frame of cast aluminum. For use in ventilating oil refineries, chemical plants, solvent rooms, etc.

59 • ***RUBBER PINCH VALVE.*** For use in the mining, paper, chemical, oil, etc., industries, a rubber pinch valve developed by the U. S. Rubber Co. for installation in pipe lines carrying abrasive or corrosive mixtures. Available in several different stocks: neoprene, where oil resistance is important; butyl rubber, for high heat and severe acid conditions; and pure gum stock for the food and beverage industries. According to the company, the flexibility of the valve will offset misalignment in pipes; no packing is required; it absorbs vibration, eliminates water hammer and eliminates galvanic action. Sizes range from 1½ in. to 12 in.

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"Corrosion Problems in Gas Purification Units Employing MEA Solutions"

By: Fred C. Riesenfeld, *Research Chemist*, and Clyde L. Bloehm, *Assistant Director of Research*

Abstract: *Experimental work is described on testing of various steels and alloys for corrosion resistance in gas-treating solutions employing monoethanolamine. A theory of such corrosion is developed. Apparatus and methods are detailed, and data are presented in tables and graphs.*

"Chemical Deterioration of Cooling Tower Lumber"

By: Clyde L. Bloehm, *Assistant Director of Research*, and Henry D. Frazier, *Research Chemical Engineer*

Abstract: *So-called "delignification" of cooling tower lumber is discussed, augmented by field observations and experimental data.*

"Effect of Pulsation on Gas Measurement"

By: C. F. Yates, *Research Engineer*

Abstract: *This paper discusses the effect of pulsative flow on the accuracy of measuring gas flow rate by orifice meters. Data are presented showing the relationship between magnitude and nature of the pulse and the resultant readings recorded by the measuring instrument.*

"Fractionating Absorbers in the Petroleum Industry"

By: J. C. Hannah, *Process Engineer*

Abstract: *Rapidly changing conditions necessitate familiarity with all methods now in use in the petroleum industry for separating mixtures of low-boiling hydrocarbons and associated compounds in order to obtain the most economic method for a given gas recovery and/or purification problem. This paper discusses one of these methods, i.e., fractionating absorbers. An example of application to actual plant data is shown.*

"Mechanical Vibration of Piping Induced by Gas-Pressure Pulsations"

By: R. C. Baird, *Research Engineer*, and I. C. Buchtold, *Director of Research and Development*

Abstract: *The generation and nature of gas-pressure pulses from reciprocating compressor action are described, together with the propagation of such pulses through pipe lines. The means whereby pulse energy is converted to mechanical vibration is discussed by the aid of analogous mechanical, acoustical, and electrical oscillatory systems. The economic importance of minimizing vibration in compressor and compressor-dependent installations is indicated.*

"A Critical Analysis of Methods of Determination of Water Dew Point in Hydrocarbon Gases"

By: F. C. Riesenfeld, *Research Chemist*, and H. D. Frazier, *Research Chemical Engineer*

Abstract: *The authors have found that the values obtained from conventional dew point determination apparatus do not give true results when used on gases effluent from liquid dehydrators. A theoretical explanation for this phenomenon and a description of a method for determining the absolute water content of gases from this type of dehydrator is offered.*

"Purification and Dehydration of Gases"

By: C. L. Bloehm, *Assistant Director of Research*, and W. P. Chapin, *Process Engineer*

Abstract: *This paper covers the chemistry and chemical engineering of regenerative processes for removing hydrogen sulfide and carbon dioxide from gases by use of amine processes together with their simultaneous or subsequent dehydration. In addition there is presented a description of the engineering features and operation of the Glycol-Amine plants which treat gas transported through the Texas-California line.*

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Fire . . . accident . . . theft . . . explosion insurance . . . you've got them all and many others, but unless your absorption and reaction towers are properly designed and made of General Ceramics Stoneware or Porcelain . . . *You're still wide open for costly losses!*

Correct in every detail . . . General Ceramics Chemical Stoneware Towers are *really built to do their job* . . . provide complete protection against every form of corrosive action except, of course, HF and strong hot caustics.

No matter what your corrosion problems may be . . . General Ceramics has both the equipment and the experience to provide the right solution. For additional information on General Ceramics Towers, write for Bulletin HA and Drawing B-2777. For information on other General Ceramics corrosion-proof equipment . . . Chemical Stoneware (Ceraware), Porcelain (Cerawite), any one of the offices listed below will be glad to forward you the necessary information. Ask for Bulletins CHER-3 and POR.

YOU SAVE 3 WAYS WITH GENERAL CERAMICS' SSS*

Savings through uniformity of construction . . . no misfits.
Savings on shipping costs . . . one shipment for everything.
Savings on paper work, accounting . . . one order, one bill.

General Ceramics AND STEATITE CORP.

CHEMICAL EQUIPMENT DIVISION

35 Crows Mill Road — Keasbey, New Jersey

Sales Offices in: BUFFALO, CHICAGO, LOS ANGELES, PITTSBURGH, PORTLAND, ORE., SAN FRANCISCO, SEATTLE, TACOMA, MONTREAL, TORONTO, VANCOUVER, B. C.

Our Insulator Division Manufactures Steatites, Porcelains, Titanates, Ferrites

*Single Source of Supply.

6367

INDUSTRIAL NEWS

(*Continued from page 27*)

CROP PROTECTION CHEMICALS BY MATHIESON

Mathieson Chemical Corp. began production last month of agricultural insecticides and fungicides at Little Rock, Ark.; Williamston, N. C., and Houston, Tex. These three new plants will contribute substantially to the nation's supplies of crop protection chemicals, according to S. L. Nevins, vice-president and director of agricultural chemicals sales.

All the new units will be located in convenient proximity to Mathieson's fertilizer plants or distributing warehouses in those cities, and their readily accessible truck-loading facilities will enable customers to pick up a combination load of fertilizers and insecticides at the same time.

Manufactured in accord with the recommendations of agricultural colleges, experiment stations and extension services, strict laboratory controls will be maintained to assure that each product manufactured is in accord with Federal and State label requirements. The products will be marketed under the Gro-More and White Diamond brand names.

HEAT TRANSFER SYMPOSIUM ON WEST COAST

The third symposium of the Heat Transfer and Fluid Mechanics Institute will be held in the Institute of Aeronautical Sciences Building, 7660 Beverly Boulevard, Los Angeles, on June 28, 29, and 30, 1950. The Institute is primarily concerned with the fundamental aspects of fluid flow and heat transmission.

Information can be obtained by writing to: 1950 Heat Transfer and Fluid Mechanics Institute, 3076 Engineering Bldg., University of California, Los Angeles 24, Calif.

FORMICA PLANS $7,000,000 EXPANSION PROGRAM

The launching of a $7,000,000 expansion program, with plans to build on a 125-acre site in Cincinnati, Ohio, was announced by D. J. O'Conor, president of The Formica Co.

The company expects to break ground this month for the first phase of construction—a one-story industrial plant providing 100,000 sq. ft. of floor space. This building will house finishing, inspection, packing, shipping and raw material warehousing facilities for the company's decorative laminated plastic products.

Approximately 200 of the firm's 1500 employees will be transferred when construction is completed late in 1950.

SHELL FELLOWSHIP PROGRAM EXTENDED

The graduate Fellowship Program established by Shell Oil Co., and its affiliated companies in the United States, has been extended through the 1950-51 academic year at a cost of $75,000. Included among the fields is chemical engineering and the colleges and universities to which Fellowships in this field have been offered are responsible for the selection of the Fellows and the departments concerned determine the specific research to be undertaken. Colleges and universities to which these Fellowships have been offered in chemical engineering are as follows:

Carnegie Institute of Technology
University of Delaware
Georgia Institute of Technology
University of Illinois
University of Michigan
Ohio State University
Pennsylvania State College
Purdue University
University of Wisconsin

NEW INSTRUMENTS TO FEATURE A.S.T.M. EXHIBIT

New testing and scientific equipment will feature the 1950 Exhibit of Testing Apparatus and Related Equipment to be held in Atlantic City, N. J., during the week of June 26 when the American Society of Testing Materials holds its 53rd annual meeting. In addition to the improved types of physical and chemical testing instruments, many of the newer types of spectrographs, nondestructive testing instruments, and equipment for stress analysis will be shown.

INDUS. SPECTROGRAPHY AT BOSTON COLLEGE

A two-weeks' course in Modern Industrial Spectrography will be offered at Boston College, Boston, Mass., from July 24 to Aug. 4. Especially designed for chemists and physicists from industries in the process of installing spectrographic equipment, this course of lectures and practical work will serve to train present personnel to man these new laboratories.

The lectures will cover the following topics: the optics and adjustment of grating spectrographs; optics and adjustment of prism spectrographs; origin of atomic spectra; light sources and the proper illumination of the spectrograph and analytical applications.

The tuition fee is $100. Applications and requests for further information should be sent to: Prof. James J. Devlin, S. J. Physics Department, Boston College, Chestnut Hill 67, Mass.

Never underestimate your cost of material handling by old fashioned methods

You undoubtedly buy the finest production machinery that is made. However, production and cost accounting authorities agree that the most important way to effect savings today is to effect economies in materials handling.

Regardless of whether you measure in pounds, tons, dollars or all three, material handling cost is one of today's most serious problems of business in general and your business in particular.

HOW AJAX LO-VEYORS CUT COSTS

Exclusive Ajax Lo-Veyor design is responsible for low cost handling of bulk materials and equally important low maintenance cost, — and here's why:

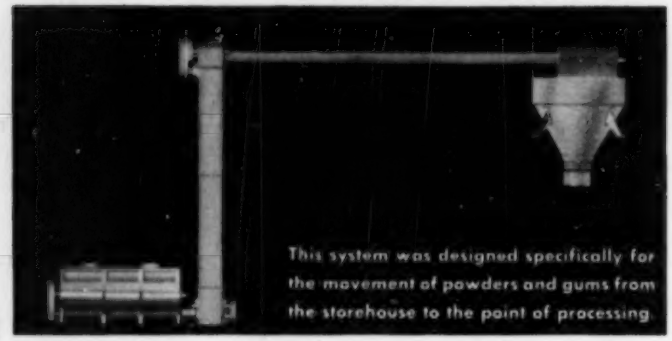
1. Only three basic parts — pan or tube . . . vibrating mechanism . . . motor.
2. Completely self-contained — ready for use.
3. No exposed bearings, no eccentric shafts, no idler and tail pulleys.
4. Pan or tube made of ferrous or non-ferrous metal.
5. Covered pan or tubular Lo-Veyors provide gas-tight construction for critical processes and explosive operations.

Used by leading chemical, food, foundry and other manufacturers.

Write giving outline and sketch of your requirements for handling dry materials.

AJAX FLEXIBLE COUPLING CO. INC. WESTFIELD, N. Y.

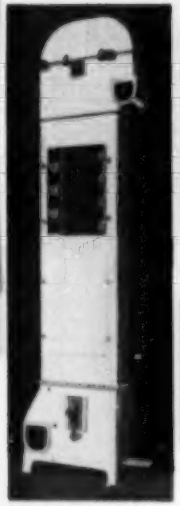
READ SOLVES MATERIAL HANDLING PROBLEM


This system was designed specifically for the movement of powders and gums from the storehouse to the point of processing.

The above Read Material Handling System was engineered and built for a New York chemical company that manufactures adhesives.

PLAIN DUMP BIN

SCREW CONVEYOR



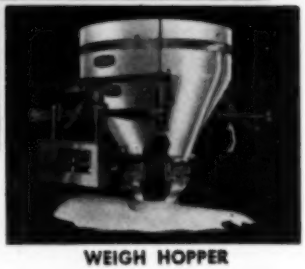
BUCKET ELEVATOR

Complete Read Material Handling Systems are "tailored" to meet your particular material and plant requirements. Each system is carefully designed with an eye to lowering processing costs by preventing the loss of material in handling and increasing the efficiency of your overall operation.

In addition, each unit in a Read System is designed and constructed for easy accessibility and cleaning . . . your assurance of maximum equipment sanitation in your plant.

For a material handling system tailored to solve your particular problems, contact Read. One of our engineers will be glad to study your plant operation and make recommendations without obligation.

CONE SIFTER



WEIGH HOPPER

READ

READ MACHINERY DIVISION
of The Standard Stoker Company, Inc.
YORK 5, PENNSYLVANIA

CHEM. INDUSTRY COMM. OF A.S.A. ORGANIZED

Organization of a chemical industry correlating committee was recently announced by the American Standards Association, New York, N. Y. The committee will serve to coordinate the views of the chemical industry on those standards that deal with equipment and products the industry uses in construction, maintenance, and operation of its production facilities. Its studies are expected to include pipe, pipe fittings and flanges, thin-wall tubing, pressure vessels, and similar products.

Two immediate objectives have been announced: first, a review of all standardization projects under the procedure of the ASA to determine those in which the chemical industry has an important interest; second to determine the extent to which the chemical industry is already represented on ASA committees.

J. G. Henderson, Carbide and Carbon chemicals division, Union Carbide and Carbon Corp., South Charleston, W. Va., is chairman of the committee. James C. Lawrence, engineering department, Du Pont Co., is vice-chairman (*see* Personalia) and C. E. Hilton, ASA, will serve as secretary.

G. E. SPONSORS X-RAY RENTAL PLAN

A service plan to rent X-ray equipment to industry without an investment in equipment, is a new plan of the General Electric X-Ray Corp., Milwaukee, Wis.

Industry will be offered a "packaged" X-ray service of equipment, maintenance, repair parts, tubes and instruction covered by one monthly charge.

According to J. H. Smith, company president, this follows a "trend in the industrial field toward service-and-rental systems." Some industries expected to use the plan are food processors and research and process control laboratories using X-ray diffraction for qualitative and quantitative analysis of chemical compounds and metallurgical processes.

BACK ISSUES WANTED

Chemical Engineering Progress is still buying the April and May issues of 1947. For these we will pay 75 cents each.

We need copies of these issues and of January, 1949, in order to supply the demand for complete volumes of back issues and also to supply the demand for complete volumes for 1949. For January, 1949, issues we will pay 50 cents.

LOCAL SECTION NEWS

(*Continued from page 25*)

CHICAGO

The annual student night meeting was held at the Western Society of Engineers April 19, 1950. Chemical engineering students of Illinois Institute of Technology and Northwestern University were guests at the dinner and program. Total attendance was approximately 140. The objective of the program was to obtain the student viewpoint on four vital and controversial issues, and to compare it with present industrial and academic consideration of the subjects. A panel of four students from the two schools prepared the major part of the program with Dr. Marvin C. Rogers, director of research for the R. R. Donnelly Co. and a local section member, as moderator. Each student first presented a short talk on his subject which was followed by several questions from the speakers and answers from the audience. Subjects and speakers were:

1. Strength and Weaknesses of Chemical Engineering Curricula—R. L. Opila, Ill. Inst. of Technology
2. What Are the Most Important Qualifications for a Graduating Chemical Engineer?—James Lawley, NTI
3. Employment Possibilities for Graduating Chemical Engineers—W. P. Shefcik, Ill. Inst. of Technology
4. What Should the Graduating Chemical Engineer Expect in the First Two Years of His Industrial Work?—Bern Schepman, NTI

Reported by Donald A. Dahlstrom

CENTRAL VIRGINIA CHEMICAL ENGINEERS' CLUB

The Club held a dinner meeting at Hotel General Wayne in Waynesboro, May 5, 1950, at which 38 persons were present. Stephen L. Tyler, Executive Secretary of A.I.Ch.E. spoke on "Activities of the A.I.Ch.E." He first discussed the growth of membership in the A.I.Ch.E. and followed this with a review of the Institute's publication activity, "Chemical Engineering Progress." Mr. Tyler then described the activities of several of the Institute's committees and concluded with a survey of the various activities of local sections. In a discussion period, Mr. Tyler answered questions relating to this Club's interest in becoming a local section of the A.I.Ch.E.

The club held a previous meeting at the Monticello Hotel in Charlottesville. Approximately 40 persons were present at dinner. Dr. R. A. Shive of the Calco chemical division of American Cyanamid Co. spoke on protective coatings as engineering materials.

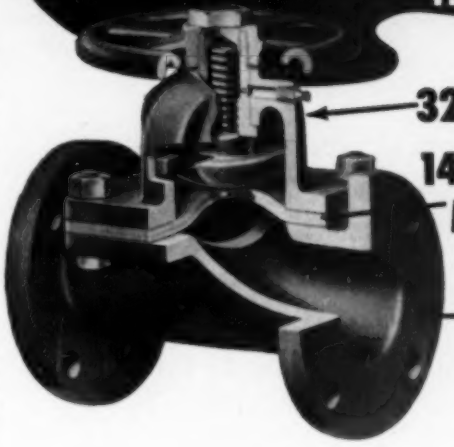
Reported by J. D. Detlefsen

(*More Local Section News on page 36*)

Hills-McCanna offers

Over 20,000

different assemblies for valving "hard-to-handle" fluids



All the various possible combinations of bonnet assemblies, diaphragms and body materials available in Hills-McCanna valves total over 20,000! True, many of the combinations would not be practical, but this figure does indicate the tremendously wide variety of valves that Hills-McCanna offers. No matter how specialized your problem of valving corrosive and/or hazardous substances, slurries, viscous liquids, gases, fermentation products, materials subject to coagulation, foods or beverages, the chances are that Hills-McCanna can furnish the proper valve to meet your needs.

Hills-McCanna valves are Saunders patent diaphragm valves wherein the closure is affected by pressing a resilient diaphragm against a transverse weir. Working parts are isolated from the flow. The valve is leak-tight and requires no packing. Sizes from 3/8" to 14".

Write, today, for full information and descriptive literature, HILLS-McCANNA CO., 2438 W. Nelson St., Chicago 18, Ill.

HILLS-McCANNA

Saunders patent diaphragm valves

Proportioning Pumps

Force-Feed Lubricators • Magnesium Alloy Castings

TREASURER'S REPORT

The accompanying balance sheet and statement of income and surplus have been examined by F. W. Lafreniz & Co., certified public accountants of 100 Broadway, New York, N. Y., and in their opinion present fairly the financial position of the American Institute of Chemical Engineers at December 31, 1949, and the results of its operation for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

C. R. DE LONG, *Treasurer.*

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
COMPARATIVE BALANCE SHEET,
DECEMBER 31, 1949 and 1948

Assets

	1949		1948	
Current Assets:				
Cash on hand and demand deposits		$ 97,736.43		$ 74,915.31
U. S. Government and other bonds, at cost plus accrued interest (Total market value and redemption value 1949, $61,596.75; 1948, $64,700.75)		61,049.36		64,703.36
Accounts Receivable:				
Membership dues, less reserve for doubtful accounts	$ 770.87		$ 687.40	
Entrance fees	100.00		145.00	
Advertising	2,847.62		1,512.15	
Publications and other charges	606.72		2,161.23	
Meetings advances	3,912.75	8,237.96	400.00	4,905.78
Inventory, at cost:				
Paper stock	$ 9,854.96		$ 7,199.46	
Stamped envelopes	518.38	10,373.34	.....	7,199.46
Total Current Assets		$177,397.09		$151,723.91
Deposits:				
United States Post Office	$ 707.22		$ 343.56	
United Airlines, Inc.	425.00	1,132.22	425.00	768.56
Furniture and fixtures, at cost	$ 13,447.68		$ 12,388.04	
Less reserve for depreciation	5,553.41	7,894.27	4,208.64	8,179.40
Total		$186,423.58		$160,671.87

Liabilities

Current Liabilities:				
Accounts payable:				
Printing and other expenses		$ 11,168.05		$ 9,290.73
Total current liabilities		$ 11,168.05		$ 9,290.73
Deferred Income:				
Dues paid in advance	$ 63,106.55		$ 60,224.55	
Subscriptions	13,381.76		9,661.36	
Other payments received in advance	355.20	76,843.51	82.47	69,968.38
Reserves:				
Chemical Engineering Education Projects Fund	$ 2,184.39		$ 1,445.09	
Student Meetings Fund	41.26		41.26	
Magazine Publication Program	13,871.16	16,096.81	19,910.79	21,397.14
Surplus		82,315.21		60,015.62
Total		$186,423.58		$160,671.87

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
COMPARATIVE STATEMENT OF INCOME AND SURPLUS
For the Years Ended December 31, 1949 and 1948

	1949		1948	
INCOME:				
Membership dues	$137,258.00		$103,411.27	
Less amount allocated to subscriptions @ $4.50 per member	42,069.75	$ 95,188.25	38,077.13	$ 65,334.14
Entrance fees		12,450.00		11,795.00
Magazine income		153,840.60		154,000.74
Publication sales:				
Transactions sales to The Institution of Chemical Engineers			$ 1,305.71	
Bound volumes and Transactions	$ 1,430.03		1,671.99	
Other	27.50	1,457.53	171.45	3,149.15

	1949		1948	
Institute Meetings:				
Surpluses	$ 2,059.46		$ 1,725.91	
Less Officer's expenses	658.73	1,400.73	511.49	1,214.42
Emblem sales	$ 3,102.25		$ 3,536.25	
Less purchases	2,239.02	863.23	2,536.07	1,000.18
Interest on investments		1,933.50		1,688.50
Total Income		$267,133.84		$236,382.13
EXPENSES:				
General operations:				
Magazine expenses	$ 97,103.16		$109,454.62	
Salaries	93,090.22		85,526.98	
Rent and Electricity	12,564.70		8,434.58	
Postage	5,552.59		4,533.65	
Telephone and Telegraph	2,250.34		2,093.86	
Stationery and office supplies	2,052.77		2,420.77	
Auditing	1,310.50		945.38	
Moving expenses			2,726.00	
Travel	1,673.13		3,533.92	
Provision for depreciation of furniture and fixtures	1,344.77		1,238.81	
Provision for doubtful accounts	2,326.53		715.10	
Miscellaneous	2,703.33	$221,972.04	2,916.33	$232,552.00
Institute Meetings:				
Programs	$ 4,387.16		$ 4,014.23	
Travel	1,845.58		1,539.05	
Reporting service	779.63		1,061.98	
Other	346.62	7,358.99	304.31	6,919.57
Transactions of Institution of Chemical Engineers purchased		11,411.08		2,285.41
Printed Material:				
Directory	$ 372.30		$ 5,654.72	
Ballot booklets, letterheads, envelopes, etc.	5,251.64	5,623.94	5,125.81	10,780.53
Participations and Contributions:				
Engineers' Council for Professional Development	336.50		$ 300.00	
Engineers' Joint Council	232.50		21.00	
The Chemists' Club Library	100.00		100.00	
Engineering Societies Library	100.00		.....	
American Society for Engineering Education	50.00		50.00	
U. S. National Committee on Theoretical and Applied Mechanics	50.00		.....	
American Documentation Institute	25.00	$ 894.00	.....	$ 471.00
Committee Appropriations:				
Council	406.61		$ 393.39	
Admissions	531.91		587.27	
Advisory Membership	.....		311.73	
Awards	315.79		262.63	
Chemical Engineering Education and Accrediting	250.63		1,472.38	
Chemical Engineering Education Projects	.....		17.00	
Constitution and By-Laws	424.11		22.66	
Local Sections	95.44		83.99	
Patents	200.00		13.54	
Program	114.56		127.36	
Public Relations	152.74		199.75	
Student Chapters	1,132.02	3,613.83	507.56	4,100.76
Total Expenses		$250,873.88		$246,109.29
Net Income (Deficit) for year		$ 16,259.96		($ 9,727.16)
Surplus at Beginning of year		79,926.41		89,653.57
		$ 96,186.37		$ 79,926.41
Deduct:				
Reserve for magazine publication program		$ 55,000.00		$ 55,000.00
Less net expenditure to end of year		41,128.84		35,089.21
Magazine publication program		$ 13,871.16		$ 19,910.79
Surplus at end of year		$ 82,315.21		$ 60,015.62

SECRETARY'S REPORT

S. L. Tyler

The Executive Committee met May 12 at the Institute offices in New York with T. H. Chilton, presiding, C. R. DeLong and S. L. Tyler present. L. W. Bass was present as guest.

After acting upon the Minutes of the previous meeting, April 6, the Treasurer's report and bills, they proceeded to the other special agenda items for this meeting.

The Secretary reported on the first listing in Chemical Engineering Progress of the names of applicants for membership that no adverse comments had been received regarding any of the applicants. It is indeed an indication of the excellent work of the Committee on Admissions. It was therefore voted that all those whose names were listed should be elected to the grades of membership as indicated.

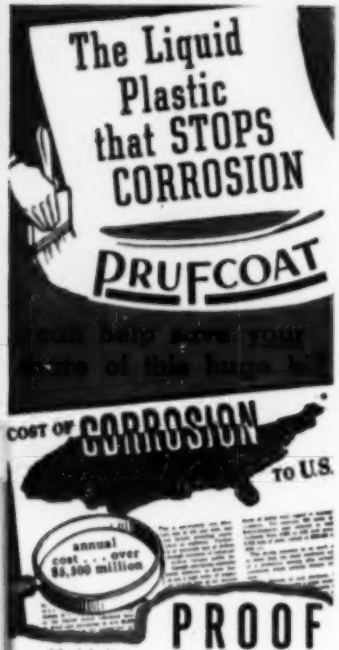
Upon recommendation of the Chairmen several additional committee appointments were made.

The financial report had been received from the Committee for the Annual Meeting at Pittsburgh in December, 1949, which showed a surplus from the activities of that meeting of $1,812.40, which the Executive Committee voted to credit to the Institute Meetings Account.

Upon recommendation of J. S. Walton, Chairman of the Student Chapters Committee, D. S. Cryder was appointed as counselor of the student chapter at Pennsylvania State College and B. J. Lerner as counselor of the student chapter at the University of Texas.

Resignations were received and accepted from five Junior Members and three Associate Members.

The agenda for the Council Meeting was reviewed in a preliminary way and several other matters of policy discussed but no actions taken.


The Liquid Plastic that STOPS CORROSION
PRUFCOAT
can help save your share of this huge loss
COST OF CORROSION TO U.S.
annual cost . . . over $5,000 million

PROOF against Acids, Alkalis, Salt, Oil and Water

*Article in C. & E. News Vol. 27 — #39

"Prufcoat proven superior to all other coatings we have tested" . . . writes one of America's largest chemical companies, after eight years' experience with Prufcoat. And this is just one of many reports on file testifying to the effectiveness of Prufcoat's famous liquid plastic formulations in controlling corrosion caused by chemical agents such as these:

Acetic Acid	Muriatic Acid
Alcohols	Nitric Acid
Bleach Solutions	Oleic Acid
Calcium Chloride	Oleum
Chlorine	Phosphoric Acid
Cyanides	Salt Solutions
Formaldehyde	Sugar
Hydrofluoric Acid	Sulfonated Oils
Lactic Acid	Sulphuric Acid
Lubricating Oils	Sodium Hydroxide

Send today for a *Prufcoat PROOF Packet*. Contains in one easy-to-file folio outside laboratory tests, case histories, and Prufcoat Protecto-Graph Plan for analyzing your own painting maintenance costs. *Write Prufcoat Laboratories, Inc., 63 Main St., Cambridge 42, Mass.*

SAVES More because it PROTECTS More

8 Attractive Colors that Apply Like Paint to Masonry, Metal, Wood

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

George E. Holbrook

Room 7406 Nemours Bldg.,
E. I. du Pont de Nemours & Co.,
Wilmington, Del.

MEETINGS

Regional — Minneapolis, Minn., Radisson Hotel, Sept. 10-13, 1950.

Technical Program Chairman: E. L. Piret, Minnesota Mining & Mfg Co., Minneapolis, Minn.

Annual—Columbus, Ohio, Neal House, Dec. 3-6, 1950.

Technical Program Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio

Regional — White Sulphur Springs, W. Va., The Greenbrier, March 11-14, 1951.

Technical Program Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.

Regional—Kansas City, Mo., Hotel Muehlebach, May 13-16, 1951.

Technical Program Chairman: Walter W. Deschner, J. F. Pritchard Co., Kansas City, Mo.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

SYMPOSIA

Indoor vs. Outdoor Plant Construction

Chairman: J. R. Minevitch, E. B. Badger & Sons Co., 75 Pitts St., Boston, Mass.

Meeting—Minneapolis, Minn.

Chemical Engineering Fundamentals

Chairman: Mott Souders, Shell Development Co., 100 Bush St., San Francisco, Calif.

Meeting—Minneapolis, Minn.

Chemical Engineering Kinetics

Chairman: R. H. Wilhelm, Princeton (N.J.) University

Meeting—Minneapolis, Minn.

Chemical Engineering in Food Industries

Chairman: W. L. Faith, Corn Products Refining Co., Argo, Ill.

Meeting—Minneapolis, Minn.

Phase Equilibria

Chairman: W. C. Edmister, Carnegie Inst. of Tech., Pittsburgh, Pa.

Meeting—Minneapolis, Minn.

What Should You Know About Management?

Chairman: L. P. Scoville, Jefferson Chemical Co., Inc., 711 Fifth Ave., New York 22, N. Y.

Meeting—Minneapolis, Minn.

Air and Water Pollution Control

Chairman: Richard D. Hoak, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

Meeting—Columbus, Ohio

Relationship Between Pilot-Scale and Commercial Chemical Engineering Equipment

Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.

Meeting—White Sulphur Springs, W. Va.

Chemical Engineering in Glass Industry

Chairman: F. C. Flint, Hazel-Atlas Glass Co., Washington, Pa.

Meeting—Not scheduled.

Processing of Viscous Materials

Chairman: W. W. Kraft, The Lummus Co., 420 Lexington Ave., New York, N. Y.

Meeting—Not scheduled.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, George E. Holbrook, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

SOUTHERN CALIFORNIA

The monthly dinner meeting was held May 16, 1950, at Carl's Viewpark Restaurant in Los Angeles. Members and guests present numbered 90. T. H. Chilton, Vice-President of A. I. Ch. E., whose brief visit to Los Angeles coincided with the meeting night, addressed the membership briefly.

As the program for the evening, J. R. Sabina, technical director, petroleum chemicals division, The DuPont Co., presented a paper on "Modern Fuels for Modern Engines." Mr. Sabina discussed the fuel requirements of modern engines, the chemical and physical properties of these fuels, and the effect of changes in various gasoline blending components.

Reported by William J. Baral

LOUISVILLE

This section held a dinner meeting May 17 at the Preston Kunz Restaurant. The speaker was E. J. Cleary, who is executive director and chief engineer for the Ohio River Valley Water Sanitation Commission. Mr. Cleary spoke on "Pollution-Abatement Action in the Ohio River Valley" and illustrated the subject with a movie, "Clean Waters."

The section made awards of tickets to its May dinner meeting to three chemical engineering students at the Speed Scientific School, University of Louisville, for outstanding scholarship and participating in extracurricular activities. The recipients were W. L. Aspy, W. G. Barclay and W. R. Campbell.

Reported by W. B. Altsheler

BOSTON

At the regular meeting of the year the following officers were elected:

Chairman—A. W. Fisher, Arthur D. Little, Inc.
Vice-Chairman—C. A. Stokes, G. L. Cabot, Inc.
Secy. and Asst. Treas.—H. Avery, G. L. Cabot, Inc.
Treasurer—P. M. Rinaldo, Dewey & Almy Chemical Co.

Reported by Henry Avery

EL DORADO CHEMICAL ENGINEERS' CLUB

At its April monthly dinner meeting, this club heard W. C. Dennis, division geologist of the Lion Oil Co., and John Radsdale, production engineer of the same company, jointly discuss "The Geology and Production of Petroleum." Following their talks, a film called "Oil from the Earth" was shown.

Reported by E. D. Wurster

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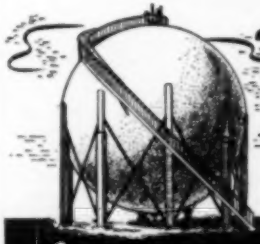

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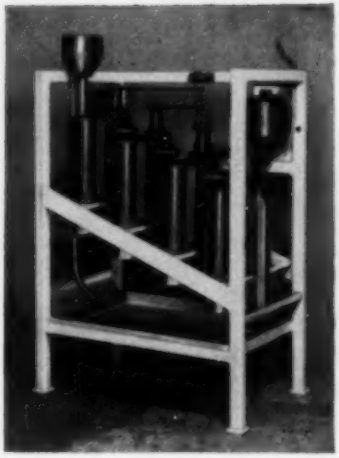

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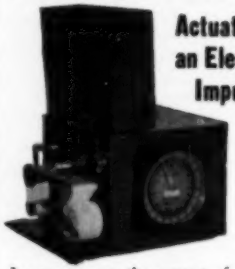

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PEOPLE

C. W. RIPPIE

Charles W. Rippie was recently elected vice-president and technical director of the American Development Corp., New York, N. Y. He has been associated with Lukens Steel Co. as a member of its sales development staff. Dr. Rippie was at one time head of the technical service of the research and development division of Merck & Co., Rahway, N. J., and had been associated also with Solvay Sales Corp., and with Monsanto Chemical Co.

Lester D. Hatch of Holbrook, Mass., was recently appointed to the sales development department of Monsanto Chemical Co.'s Merrimac division. Mr. Hatch is a graduate of Northeastern University with a B.S. degree in chemical engineering. He served with the Naval Air Force during World War II.

J. C. LAWRENCE

James C. Lawrence, supervising engineer, engineering department of the Du Pont Co., Wilmington, Del., has been named vice-chairman of the newly organized chemical industry correlating committee of the American Standards Association. **(See p. 32.)** **Mr. Lawrence has been associated with the Du Pont Co. since 1927 and served as chemical engineer before assuming the position of supervising engineer. He received his A.B. and his B.S. from the University of Missouri.**

S. D. KIRKPATRICK, J. R. CALLAHAM IN NEW DUTIES WITH McGRAW-HILL

Sidney D. Kirkpatrick, vice-president and a director of the McGraw-Hill Book Co., and editor of Chemical Engineering, has been named editorial director of that publication and of Food Industries. Mr. Kirkpatrick, who will continue as a vice-president of the book company and a director, will supervise the editorial policies of both publications.

A graduate of the University of Illinois, Mr. Kirkpatrick joined McGraw-Hill in 1921 as assistant editor of Chemical and Metallurgical Engineering, now Chemical Engineering. He became associate editor in 1925 and editor in 1928.

Mr. Kirkpatrick has been active in A. I. Ch. E. affairs—he was President of the Institute (1942), Vice-President (1941), and was a Director (1933-35, 1937-39, 1947-49).

The new editorial director has received many honors for his achievements in the engineering field—he was awarded the honorary degree of Sc.D. from Clarkson College of Technology, the D.Eng. from Polytechnic Institute of Brooklyn, and was Chemical Industry Medalist in 1945.

John R. Callaham, former executive editor of Chemical Engineering, succeeds to the post of editor. He becomes the fourth to serve in that capacity since the initial publication in 1902. Associated with McGraw-Hill since 1941, he was in charge of editorial activities for the magazine on the West Coast before his promotion in June, 1949, to the position of executive editor. A graduate of the University of South Carolina, Mr. Callaham was formerly associated with General Chemical at Marcus Hook and at various times worked for that company in Pennsylvania, New York and California.

J. R. CALLAHAM

S. D. KIRKPATRICK

MURPHREE IN NATIONAL ACADEMY OF SCIENCES

E. V. Murphree, president of Standard Oil Development Co., central technical and research organization of Standard Oil (New Jersey) was elected to membership in the National Academy of Sciences at the recent annual meeting of the Academy in Washington, D. C. Mr. Murphree, the winner of the 1950 Perkin Medal, was elected president of Standard Oil Development in 1947. He had previously served as vice-president and subsequently executive vice-president.

The National Academy of Sciences is composed of leading scientists, engineers and physicians in the United States. It also through various trust funds makes grants-in-aid to scientific workers engaged in research projects.

1950 YALE AWARD GOES TO J. D. FENNEBRESQUE

John D. Fennebresque, general manager of the chemical division of Celanese Corporation of America, received the 1950 Award of the Yale Engineering Association for "advancement of basic and applied science" at the annual dinner of the group held recently at the Yale Club, New York.

Mr. Fennebresque (Class of 1939) was cited for his work with Celanese Corporation of America in connection with the oxidation of natural gas hydrocarbons in the production of a long series of aliphatic compounds and his wartime work with the Office of the Rubber Director in initiating and carrying out into production a system of agitation as applied to copolymerizations, leading to simplification and improvement of processes for the manufacture of synthetic rubber.

The Yale Engineering Association Award is given to a university alumnus in engineering not more than 15 years out of college in recognition of work done and encouragement for further achievement.

(*More About People on page* 41)

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SITUATIONS OPEN

Jr. Chemical Market Analyst—Chemical engineer or chemist, with economic and business training, for Market Research Section, in young progressive midwestern chemical company. Headquarters in Kansas City, but position involves some traveling. Experience desirable, but not essential. Please give complete personal and professional data with salary requirements in first letter. Box 2-6.

Supervising Chemical Engineer—Chemical Engineering Degree, preferably Ph.D. 35 to 45 years of age. Approximately 15 years' experience in organic chemical industries, preferably intermediates or dyestuffs. Thoroughly experienced in applying chemical engineering principles to production problems in batch process type of industry. Permanent position in well-established company in upstate New York. Send complete business resume and salary requirements. All replies confidential. Box 3-6.

SITUATIONS WANTED

A.I.Ch.E. Members

Supervisory Chemical Engineer—B.S., 31. Experienced in supervision, operations, pilot plant development, plant design, and economic studies of petroleum and petrochemical plants. Desire responsible engineering position with small company. Box 1-6.

Chemical Engineer — Administrative Experience—Ten years responsible administrative positions with large, nationally known chemical manufacturers. Previous six years in production, development, design, construction. Successful record handling personnel. Particularly familiar inorganic processes involving gas absorption, crystallization, evaporation, drying, filtration, refrigeration. Considerable experience starting up new plants. B.S. '34, Tau Beta Pi. Age 38, married, family. Available immediately. Resumé on request. Box 4-6.

Process Engineer—Ch.E. '39. Age 37. Nine years of industrial experience. Process design experience in refinery and petrochemicals. Several years background in process control, instrumentation and pilot plant scale work. Successful development work in both chemical and equipment fields. Paper on fractionation. Patents. Interested in process engineering. Box 5-6.

Chemical Engineer—Licensed Professional—Fifteen years' diversified responsible experience on design, production and sales of chemical processes and equipment primarily organic. Desire responsible position with established company where initiative and versatility an advantage. Box 6-6.

Chemical Engineer—Age 31. Ph.D., 1946. Two years petroleum pilot plant, four years' teaching experience. Limited experience in metals and organic. Desire position in production, development or management. Box 7-6.

Teacher of Chemical Engineering—Ph.D. June 1950. Age 31, single. Five years' industrial experience, four years' teaching experience. Desire permanent teaching position with opportunity for research. Box 8-6.

Chemical Engineer—B.S. and M.S. in Ch.E. Married, 27. Industrial experience in lacquers and recovery of solvents in large company. Desire supervisory position. Location immaterial. Box 9-6.

Chemical Engineer—M.S., age 29, now employed. Six years in successful process development, chemical and food industries. Good references and academic record, honor fraternities, patents. Desire process development position in the food industry, will consider others. Prefer West Coast location. Box 10-6.

Junior Executive—Are you a small Texas manufacturer needing a young chemical engineer with interests in business, sales? To such I offer: excellent college record with graduate work, two years' technical service experience, determination to get ahead by hard work. Box 13-6.

Executive Engineer—Chemical engineer engaged in direction of group designing plants for soaps, detergents, chemicals, and pharmaceuticals. Seek position as chief engineer. In previous position had overall responsibility for projects. Metropolitan area preferred. Box 14-6.

Chemical Engineer—B.S. and M.S. Versatile and experienced. Specialized in technical writing and editing; research coordinator. Twenty years' experience with industrial minerals, inorganics, ceramics, cement, alumina, phosphates, petroleum, and others. Employments include TVA, U. S. Bureau of Mines and Battelle Memorial Institute. Unprejudiced, but prefer South or Southwest. Box 16-6.

Chemical Engineer—B.S., Lehigh 1943, single, 28. 3½ years heavy chemicals production, instrumentation, electronics troubleshooting; 3 years fine chemicals pilot plant; small-scale process development, layout, operation, supervision. Desire pilot plant; development work. Prefer Northeast. Box 17-6.

Chemical-Mechanical Engineer and Executive—Prof. Licensed New York. Twenty-five years responsible charge design, construction, operation, maintenance and administration heavy chemical industry incl. chlorine, ammonia, dry ice, alkalies, etc. Desire position in production or engineering. Box 18-6.

Registered Professional Engineer—28, Purdue, B.S.Ch.E., 1943; family, veteran. Four years petroleum catalyst research in leading industrial research organization involving bench scale design, construction, catalyst evaluation. Desire responsible position in petroleum or pharmaceutical industry. Box 19-6.

Nonmembers

Chemical Engineer—24, U. of Utah, B.S.Ch.E. Single. Desire position with progressive company. Will consider domestic or foreign employment with no geographical preference. Box 11-6.

Chemical Engineer—B.S. June 1950, single. Will relocate. Desire position production of organics, pharmaceuticals, or plastics requiring hard work and ability to work well with others. Box 12-6.

Chemical Engineer—30, B.S.Ch.E., Michigan. Nine years experience. Six years' excellent diversified pilot plant experience including catalytic cracking and synthetic fuels development. Three years as head of pilot plant department. Commercial refinery experience also. Box 15-6.

PEOPLE

(*Continued from page 39*)

A.I.C. MEDAL WINNER

W. J. MURPHY

Walter J. Murphy, American Chemical Society editor, of Washington, D. C., received the 1950 gold medal of the American Institute of Chemists at the twenty-seventh annual meeting of that Institute held May 12 at the New Yorker Hotel. The medal was presented by Lawrence H. Fleet of New York, president of A.I.C. Since 1943 Dr. Murphy has been editor of three A.C.S. publications: Chemical and Engineering News, Industrial and Engineering Chemistry, and Analytical Chemistry.

THREE DU PONT MEN GO TO LOUISVILLE

Three members of A. I. Ch. E. have recently been transferred to the Louisville (Ky.) plant of the Du Pont Co. from other plants of the company.

David G. Cushing, formerly in the Wilmington engineering department, is now in a similar capacity with the Louisville plant.

Frank B. Roberts and Robert A. Hammond, both previously connected with the Chambers Works, are in the development group.

Robert H. Kittner formerly vice-president of Glenn L. Martin's chemicals division, was recently appointed production manager of Industrial Rayon Corp., Cleveland, Ohio. A chemical engineering graduate of Case Institute of Technology, Mr. Kittner received a degree of chemical engineer from Columbia University upon completion of graduate work in 1929 and was associated with the American Hard Rubber Co. from that time until he joined the Glenn L. Martin organization. He organized Martin's chemicals division in 1944 and subsequently became vice-president in charge of that division. He resigned this year after Martin's chemicals division was bought by U. S. Rubber Co.

Edwin J. Barth petroleum technologist, has joined the Gulf Oil Corp., Pittsburgh, Pa., as a technical consultant in the general sales division.

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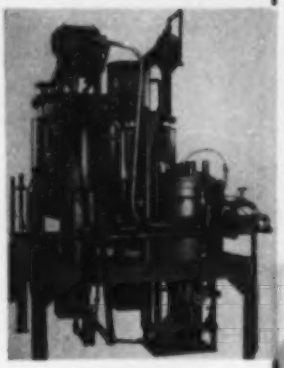

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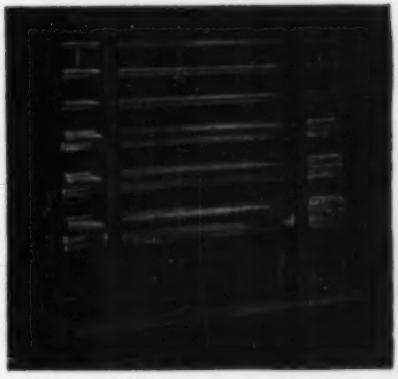

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THRODAHL ADVANCED BY MONSANTO CHEM. CO.

Appointment of Monte C. Throdahl as research supervisor in rubber chemicals was recently announced by Dr. W. P. Metzner, director of research for Monsanto Chemical Co.'s rubber service department.

Mr. Throdahl, who joined Monsanto at Nitro, W. Va., in 1941, after receiving a B.S. degree in chemical engineering from Iowa State University, served during the past year in a liaison capacity between the research and sales departments of the rubber service department. He will continue this assignment together with supervision of the rubber chemicals laboratory and will assume added responsibilities for rubber chemicals and control laboratory operations.

E. J. Kimmel has been transferred to the research department of Joseph E. Seagram and Sons, Inc., from the power house staff.

C. F. Rassweiler was elected president of the Industrial Research Institute, Inc., New York, N. Y., for the ensuing year at the thirteenth annual meeting held April 26-28 at the Westchester Country Club, Rye, N. Y. Dr. Rassweiler is vice-president for research and development of the Johns-Manville Corp., New York, N. Y.

Stanley S. Morris formerly research engineer of the Interchemical Corp., Newark, N. J., is now chief chemist of the Dobbs Chemical Co., New Haven, Conn.

Bernard Wendrow is now associated with the Mathieson Chemical Corp., Lake Charles, La. He was formerly graduate student in department of chemical engineering at the University of Texas.

Milton R. Beychok recently took the position of chief chemist with the Rothschild Oil Co.'s refineries. He is a chemical engineering graduate of Texas A. and M. College and was employed in General Petroleum's Torrance refinery and in Shell Oil's research department as a research chemical engineer.

R. L. Huntington, chairman of the school of chemical engineering, University of Oklahoma, Norman, Okla., has written "Natural Gas and Natural Gasoline," published by the McGraw-Hill Book Company, Inc. The book, Huntington's first, was written to meet the need of engineering students taking courses which deal with the production of natural gas from crude oil, condensate and dry gas fields, and the manufacture of liquefied products from this raw material.

D. M. Shapleigh is now mill manager of the Superba Mills, Inc., Hawkinsville, Ga. He was formerly general manager of the New England Forest Products, Inc., North Wilbraham, Mass.

Paul K. Mulvany recently joined the staff of the California Research Corp., Richmond, Calif., as a research chemist. He had been at the University of Washington as a teacher on a part-time basis while pursuing the degree of Ph.D.

Chester A. Snell represented Foster D. Snell, Inc., at the First United States Technical Conference on Air Pollution held at the Wardman Park Hotel, Washington, D. C., May 3-5, under the sponsorship of the Federal Interdepartmental Committee. As director of the analytical department of the firm Dr. Snell has had occasion to conduct many extensive surveys of air contamination and has presented a number of papers on the subject.

L. W. Rothenberger is now plant superintendent of the Hercules Powder Co., Klamath Falls, Ore. He was formerly assistant superintendent of the company at Hattiesburg, Miss.

Donald E. Garrett recently completed his dissertation work at Ohio State University and is now with Dow Chemical Co., at Pittsburg, Calif.

Howard A. Blyth has been transferred to the Warners Works of the American Cyanamid Co., as assistant works manager, effective July 1, 1950. Previously he held the position of group leader, chemical engineering division of the company's Stamford Research Laboratories, Stamford, Conn.

Necrology

WILLIAM H. GABELER

William H. Gabeler, manager of the phosphate rock division of the Davison Chemical Corp., Baltimore, Md., died April 29 in Bartow, Fla., where his office was located and where the company has phosphate mining interests. He was 58 years old.

Mr. Gabeler joined Davison in 1920 and was assigned to assist in the development of the phosphate rock properties of the corporation at Bartow. Subsequently he returned to Baltimore and helped in the development of several of the corporation's engineering projects, among them the commercial manufacture of silica gel and the development of various fertilizers. When the Davison corporation was chosen by the Rockefeller Foundation to make a survey of the phosphate rock industry in Brazil, Dr. Gabeler was delegated to do the job.

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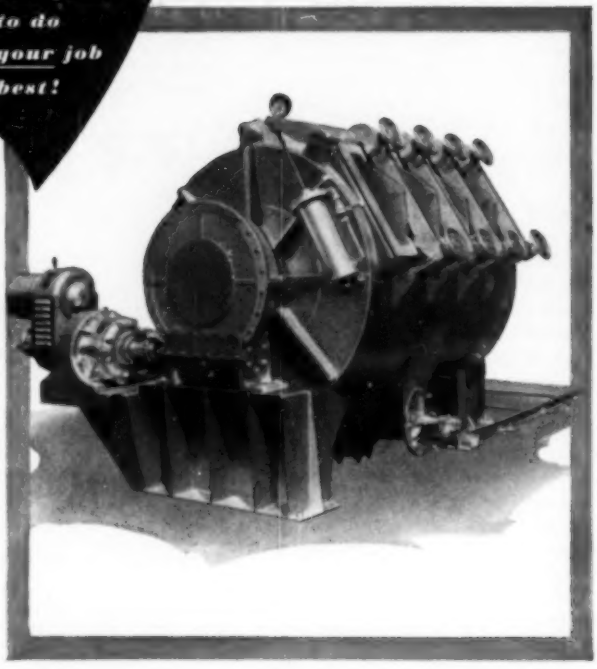
New Conkey Rotary Leaf Pressure Filter brings big advantages with "non-opening" operating cycle

Designed to do your job best!



Cyclic filtration of slow filtering slurries and clarification of suspensions

What are the big advantages of the new Conkey "non-opening" cycle operation? **Maximum labor saving obtained here! Only occasional valve manipulation needed. No worker-handling of filter cloths because the filter is not opened for cake discharge. Volatile solvents can be handled with negligible evaporation losses. Less danger to personnel from corrosive liquids. The entire filter may be insulated for operation at high or low temperatures. And the extremely compact design makes for minimum cubic footage and low installation charges.**

Rotation of leaves prevents settling. This helps build a non-tapering cake of uniform thickness and porosity for positive washing, maximum drying and clean discharge.

Other outstanding features: Filter medium may be either metal or fabric. Quick filter cloth changes are easily made by sector removal through inspection doors. Dry or sluicing cake discharge is provided for with complete cake discharge and cloth cleaning result.

To make some interesting comparisons, write for Technical Bulletin No. 105.

Other General American Equipment:
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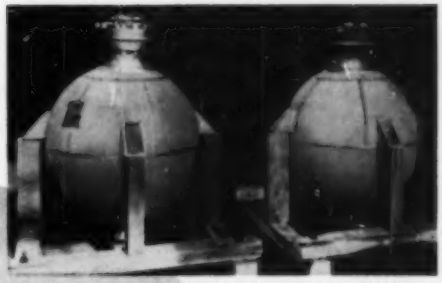
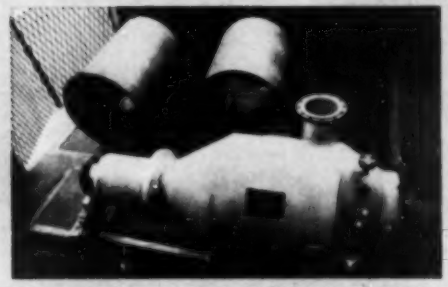
not just another TANK!



These 42" diameter 304 stainless steel spheres are for the storage of monomer chemicals, with an operating temperature of minus 58° F. and a pressure of 300 psig. The welding of the 12 spherical segments to form each tank was performed in compliance with Paragraphs U-69 and U-140 of the A.S.M.E. Code.



A vertical flash evaporator body — 12' in height, 54" and 24" in diameter, built of ¼" thick type 316 extra low-carbon stainless steel. Use of expansion joint simplified a difficult space problem on the circulating pump piping.

A horizontal esterification kettle — 34' in length by 10' 9" in diameter, built of ⅜" thick deoxidized copper, using the silver brazing process. The vessel was tested at 10 psig. and the steam chest at 250 psig. Total weight was 36,000 lbs.

Present-day equipment design of chemical process vessels frequently requires something more than just another tank. Vulcan handles many such design and fabrication problems and is providing numerous special purpose vessels to process users. Three recent examples are illustrated.

Items such as flash coolers, reactors, decanters, percolators and separators are constructed. Often storage drums and tanks require special features. Complete evaporation units, single or multiple effect, natural or forced circulation, are built. The individual items — bodies, calandrias, heat belts — also are available. Comparison on cost can be made between any of the metals — solid, clad or lined — through Vulcan's wide range of experience in alloy as well as copper and steel fabrication. Acetic acid, ethylene glycol, isopropanol, fatty acids and pharmaceuticals are typical products being handled in Vulcan-built equipment.

VULCAN distillation evaporation extraction processes and equipment

THE VULCAN COPPER & SUPPLY CO., General Offices and Plant, CINCINNATI, OHIO

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We invite you to write for a copy.

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